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Productivity, External Balance, and Exchange Rates: Evidence on the Transmission Mechanism among G7 Countries

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3.1 Introduction

A widespread view of the transmission mechanism holds that a productivity increase in the traded goods sector of a country should simultaneously lower the international relative price of domestic tradables (that is it should worsen the country's terms of trade), and raise the relative price of domestic nontradables—as predicted by the Harrod-Balassa-Samuelson (HBS) hypothesis. A host of theoretical and quantitative models built by academics, and researchers in policy institutions subscribe to this view, with far reaching implications at both theoretical and policy levels. Namely, international spillovers of productivity shocks are acknowledged to be unambiguously positive: foreign consumers benefits from an increase in the traded goods production in the domestic country via reduced import prices (Corsetti and Pesenti 2001). For this very reason, divergences in productivity levels across countries supposedly have a contained effect on relative national wealth.[1] Moreover, terms of trade movements purportedly reduce the consumption risk of asymmetric productivity shocks: even if international asset markets do not provide complete insurance, relative price movements systematically reduce the wedge between domestic and foreign wealth induced by fluctuations in relative productivity.[2] To the extent that international price movements insure consumption against production risk, the scope for welfare gains through international policy coordination may be quite limited (Obstfeld and Rogoff 2002).

However, according to standard general equilibrium open economy models, the macroeconomic effects and the international transmission of technology shocks do not need to be identical across economies that differ in structural characteristics such as openness and trade elasticities, as well as the degree of shock persistence. Depending on these features, country specific gains in productivity are not necessarily associated with a (short-run) deterioration in the international relative prices of a country's output and consumption. For instance, the above conventional wisdom is unable to account for important episodes such as the U.S. strong dollar and the U.S. terms of trade appreciation in the second half of the 1990s, which accompanied the productivity boom in this country (Corsetti and Pesenti 1999).

As the international transmission mechanism is at the core of theoretical modelling and policymaking alike, it is somewhat surprising to find limited empirical work on these issues. Taking a step towards addressing this gap in the literature, this paper analyzes the international transmission of productivity shocks in manufacturing among industrial countries. The countries in our sample—Germany, Italy, Japan, the United Kingdom, and the United States—differ in size and degree of openness.[3] For each country, structural vector autoregressions (VAR) are run to identify productivity shocks in manufacturing using long-run restrictions as in Galí (1999), Francis and Ramey (2005), and Christiano, Eichenbaum, and Vigfusson (2004). Two features are emphasized in this study. First, the study focuses on productivity shocks to the tradable sector, rather than to the economy as a whole, because the theory's predictions are starker for the former than for the latter. Specifically, the effects of economy-wide productivity shocks on domestic and international relative prices depend heavily on the distribution of the shock across sectors, making any inference on the international transmission exceedingly difficult.[4] As the bulk of exports in industrialized countries consists of manufactured products, we look at manufacturing as a natural proxy for the tradable sector. Second, whereas previous studies mostly focused on the link between productivity and real exchange rates, motivated by the HBS hypothesis, here there is a significant emphasis on the joint dynamics of net trade and different international relative prices (including the price of tradables). The analysis incorporates three measures of international relative prices between each country and an aggregate of Organisation for Economic Co-operation and Development (OECD) economies, namely, a consumer price index (CPI) based, a producer price index (PPI) based, and an export deflator based real exchange rate—the latter being constructed to proxy for the terms of trade.[5]

Overall, our baseline VAR results square well with standard models' predictions on the international transmission along many dimensions; as a general pattern, positive productivity shocks in each of the countries in our sample raise domestic manufacturing output and aggregate consumption relative to an aggregate of other industrial countries. In response to such shocks, the trade balance worsens (its deterioration being persistent over time), and the price of domestic tradables in terms of nontradables—proxied in most cases by the PPI relative to the services' CPI—falls, in full accord with the HBS hypothesis.

Most interestingly, we find that the real exchange rate's response to productivity shocks is heterogenous across countries. In the case of the United States and Japan—the two largest and least open economies in our sample—productivity gains lead to a short-run appreciation in all three measures of the international relative prices. The price response is not significant for Germany, at least in our baseline specification. In the case of the United Kingdom and Italy—the smaller and more open economies in our sample—we detect permanent depreciations.

It is worth emphasizing that, while the sign of the international price response differs across countries, in each economy all prices move in the same direction. Namely, the response of the CPI based real exchange rate has the same sign as the response of the PPI based and export deflator based real exchange rates (or terms of trade). Together with the finding that nontradables prices always appreciate in response to productivity shocks to manufacturing, this result suggests that real exchange rate movements are dominated by movements in the terms of trade (proxied by export deflator based exchange rates), rather than by the HBS effect.[6]

We verify the robustness of our results along different dimensions, particularly by modelling in levels (rather than first differences) all the variables for which unit root tests give contrasting results. For the United States and Japan, our results are unchanged under this alternative specification. However, we detect short-run real exchange rate appreciation for Germany—possibly in line with the other large countries' results—and for the United Kingdom, while the response of the real exchange rate becomes insignificant for Italy. We also verify that our results are reasonably stable over different subsamples and across specifications where one country's productivity growth is not entered as a differential with respect to the rest of the OECD economies, but in absolute terms. Finally, using the model developed in Corsetti, Dedola, and Leduc (forthcoming), we carry out some Monte Carlo experiments to assess the performance of our identification strategy on simulated time series data, obtaining fairly encouraging results.

In the United States and Japan, a productivity driven macroeconomic expansion is initially associated with stronger international prices of domestic tradables, and a trade deficit. This characterization of cyclical expansions is reminiscent of models attributing international business cycle movements to demand shocks—such as the Mundell-Fleming-Dornbusch (MFD) model. Specifically, in the MFD model with flexible exchange rate, a real (IS curve) demand boom raising output and employment, also increases imports and appreciates the currency in real terms (hence net exports are crowded out). Overall, consumption and output booms are associated with a stronger currency and an external deficit. In the MFD theoretical framework, demand shocks are driven by exogenous policy measures (fiscal policy) and/or exogenous swings in the autonomous component of consumption and investment spending—often motivated, but not modelled, in terms of changing expectations about future income or productivity.

In dynamic general equilibrium models, however, productivity shocks do affect relative prices and wealth, thus shaping consumption and investment demand. Early international real business cycle models have stressed the importance of intertemporal considerations for demand dynamics. For instance, Backus, Kehoe, and Kydland (1995) show that a persistent country-specific shock to productivity (in an economy with investment) leads to a current account deficit as domestic agents raise their consumption with permanent income as well as invest in domestic technologies. Recent quantitative and analytical literature on the international business cycle has also recognized the need to reconsider the dynamics of international prices. With incomplete markets, it is now well understood that the response of domestic absorption (demand) to persistent productivity shocks is driven by pronounced country-specific wealth effects. This response may be strong enough to cause a real appreciation, at least in the short run. Our results provide an empirical contribution to this literature.

Specifically, our overall findings for the United States and Japan question the transmission mechanism embedded in some popular dynamic stochastic general equilibrium (DSGE) models of the international economy. Our results suggest that price movements may magnify the consumption risk of productivity fluctuations, as countries with larger tradable supplies also enjoy favorable terms of trade movements. By the same token, they suggest that the sign of the international spillovers from domestic productivity shocks be negative, at least in the short run.

To appreciate the importance of our findings for policy analysis, consider the recent debate on the adjustment process associated with an hypothetical reversal of the current U.S. account. In a series of papers, Obstfeld and Rogoff (2004, 2005) argue that a drastic correction of the U.S. external balance would entail a large real depreciation of the dollar. Yet, productivity differentials in the tradable sector between the United States and the rest of the world would somewhat smooth out the adjustment; a higher supply of tradables would improve U. S. net exports, via a worsening of the terms of trade, while containing the overall rate of real depreciation via the HBS effect.

Our empirical results challenge this view in at least two respects. First, our evidence suggests that the terms of trade movements in the short and medium run are the opposite of what is postulated by Obstfeld and Rogoff (2004): our measures of the U.S. international price of tradables appreciate with productivity gains in the U.S. domestic tradable sector.[7] Second, we find that, for a prolonged period of time, productivity gains do not improve the trade balance. Once the dynamic response of absorption to productivity gains in the traded good sector is taken into account, the short- to medium-run effect on U.S. net trade is negative. By the same token, consider the claim that productivity growth in the rest of the world would unconditionally hamper the U.S. external correction, unless it is concentrated in the nontraded good sector.[8] Contrary to this claim, our VAR results suggest that productivity growth in most industrial countries (especially in Japan and Europe) is likely to raise global demand for U.S. products in the medium run, even when productivity gains are concentrated in the manufacturing sector. The effect on the U.S. trade balance would clearly be positive—in accord to standard models' predictions, that higher growth and productivity in Europe and Japan would help correct current global imbalances.

The paper is organized as follows. Section 3.2 reviews the international transmission mechanism in standard theoretical and quantitative models, identifying alternative views and empirical predictions. Section 3.3 describes the data and the empirical methodology. Section 3.4 presents and analyzes in detail our main results. Section 3.5 discusses whether our identified impulse responses correctly reproduce the international transmission in Monte Carlo experiments. Section 3.6 concludes, deriving policy implications. Appendix A describes the data in detail. Appendix B specifies the model used in the Monte Carlo experiments in section 3.5.

3.2 Productivity, International Prices, and the Current Account: A Theoretical Perspective

A common view of the international transmission of country-specific productivity growth is that a higher supply of domestic tradables is absorbed by international markets at a lower price. In this section, we reconsider the theoretical underpinning of such a view. Specifically, we argue that the international transmission mechanism envisaged by standard theory generates a much richer macroeconomic and relative price dynamics. To do so, we will initially refer to well-known general equilibrium models of the international economy, including both nontradables and country-specific tradables (e.g. Obstfeld and Rogoff 2000). We will also briefly discuss recent models allowing for firms' entry and market dynamics.

3.2.1 *The International Transmission Mechanism with High Consumption-Risk Insurance.*

According to standard theory, productivity gains in the tradable sector raise the price of non tradables relative to tradables—as predicted by HBS—and change the country's terms of trade. The overall response of the real exchange rate will depend on the relative magnitude of the movements in these prices, the HBS effect tends to appreciate the real exchange rate, and if the terms of trade worsens, this tends to depreciate it. What does the sign and magnitude of the terms of trade response depend on?

A key role is played by the structure of international asset markets and the degree of international consumption insurance. When models are developed under the assumption of complete risk sharing, this assumption implies an important restriction on terms of trade and real exchange rate movements. As is well known, efficient consumption-risk insurance implies that the ratio of marginal utility of consumption across two countries is proportional to the bilateral real exchange rate between these countries. In other words, domestic consumption rises relative to foreign consumption only if its relative price—the real exchange rate—is depreciating. To see the implications of this condition for the international transmission mechanism, recall that positive productivity shocks to tradables increase the price of home nontradables through the HBS effect, and ceteris paribus, this leads to a real appreciation. Thus, for domestic consumption to rise, the terms of trade must worsen enough to more than offset the nontradable price increase, causing an overall depreciation of the real exchange rate.[9] It follows that models assuming a high degree of consumption insurance necessarily subscribe to the conventional wisdom about the international transmission mechanism stated previously—that a higher domestic supply of tradables lowers their international price (Obstfeld and Rogoff 2000).

It also follows that terms of trade depreciation, in response to positive productivity shocks, are predicted by models assuming incomplete markets, yet implying allocations that are close to the first best—i.e. predicting a counterfactual positive and high correlation between relative consumption and the real exchange rate. This is an important lesson from influential contributions which have contrasted complete and incomplete market models, showing examples where the models are remarkably close to each other in regards to the equilibrium allocations and the transmission mechanism (Cole and Obstfeld 1991; Baxter and Crucini 1995; Chari, Kehoe, and McGrattan 2002; and Corsetti, Dedola, and Leduc, forthcoming).

3.2.2 The International Transmission Mechanism with Low Consumption-Risk Insurance

When markets are incomplete, however, it is no longer true that relative consumption can increase only in the presence of real depreciation. Productivity gains drive a wedge between domestic and foreign wealth; if this (endogenous) wedge is large, productivity shocks cause substantial asymmetric effects on domestic demand relative to foreign demand. With large movements in relative domestic absorption, the terms of trade response can even change sign, relative to the complete market allocation; by the same token, a rise in relative consumption is not necessarily associated with real exchange rate depreciation, but can be accompanied by real appreciation—consistent with a large body of evidence (Backus and Smith 1993; Kollmann 1995; and Ravn 2001). With incomplete markets, the international transmission mechanism thus depends on a key set of structural parameters, including the persistence of shocks and trade elasticities.

Dynamic Response to Persistent Shocks First consider the case in which productivity innovations are very persistent and/or anticipated. The macroeconomic dynamic response to these shocks is, in part, consistent with the above conventional wisdom about the international transmission. Namely, in the long run, the terms of trade unambiguously depreciate relative to the initial equilibrium as new capital is installed and becomes productive, and productivity is at its new, higher levels; correspondingly, the trade balance improves. In the short run, however, because of inefficient consumption risk insurance, relative domestic wealth and absorption increase markedly in anticipation of future output gains. A strong response in domestic absorption raises demand for domestic tradables relative to supply, opening a trade deficit. Under some conditions, the short-term surge in absorption can actually cause temporary equilibrium appreciation of the terms of trade.

Related studies (Corsetti, Dedola, and Leduc forthcoming) analyze the above transmission mechanism in a standard DSGE model with traded and nontraded goods (and internationally incomplete asset markets) in which productivity shocks, though falling short of having a unit root, are somehow more persistent than what it is usually assumed in business cycle models. It is shown that the model can, indeed, generate terms of trade and real exchange rate appreciation in response to those very persistent productivity shocks to tradables, under the following conditions. First, the economy has a sufficiently high degree of home bias in absorption—calibrated in line with the U.S. economy—so that the response in spending to a shock raising wealth falls to a large extent on domestically produced goods (the economy is relatively closed to trade). Second, the long-run price elasticity of domestic tradables is relatively high—close to the estimates by trade economists (Bernard et al. 2003). This is because the higher the price elasticity, the smaller the long-run fall in the international price of domestic goods required to accommodate an increase in their supply. With a high elasticity, the effects of adverse relative price movements on the international value of domestic output and domestic wealth are contained. Third, agents can only borrow and lend in international markets.

Under these conditions, standard DSGE open economy models predict that the dynamic response of the terms of trade to long-lasting productivity innovations consists in short-run appreciation, followed by depreciation in the long run. Observe that terms of trade spillovers are positive in the long run, but negative in the short run when the upsurge in domestic absorption driven by expectations of future productivity gains (and financed in international capital markets) raises the international price of domestic tradables, hurting foreign consumers. These results are obtained by assuming shocks are very persistent, yet stationary. A fortiori, similar results obtain if shocks are permanent, or are anticipated, as shown in the Monte Carlo experiments in section 3.5.

The Role of Price Elasticities A variety of aggregate time series estimates pick up a very low price elasticity of imports (e.g. Hooper, Johnson, and Marquez 2000). Combined with a realistic degree of home bias in absorption, a low price elasticity of imports has important general equilibrium implications. Namely, wealth effects from terms of trade movements can be so strong that productivity gains raise, rather than lowering, the international price of a country's tradable output. An intuitive explanation (discussed at length in Corsetti, Dedola, and Leduc, forthcoming) follows. Provided that domestic consumers and firms are the largest buyers of domestic goods (home bias is strong), an increase in the global demand for these goods is possible only if domestic private income and absorption rise enough. A fall in the terms of trade, however, tends to reduce domestic wealth and income, as the selling price of domestic tradables determines the value of domestic output. If income effects are strong enough, relative to substitution effects because of a low price elasticity, the terms of trade deterioration would cause a shortfall in the global demand for domestic goods. Then, an increase in domestic supply must be associated with an equilibrium appreciation in the terms of trade.

Different from the analysis in the previous subsection, if the elasticity remains sufficiently low in the long run, the response of the terms of trade needs not change sign over time—i.e. there is no long-run depreciation. The terms of trade appreciate and domestic absorption booms on impact, opening a real and nominal trade deficit (if the appreciation is not too large). Welfare implications are starker. With a low elasticity, spillovers are unambiguously negative at all time horizons, and for any degree of shock persistence. Strong wealth effects imply that a country can capture most of the domestic gains in productivity in both the short and the long run, independently of the possibility of intertemporal trade. In contrast, with high elasticity and persistent shocks, terms of trade movements tend to create positive (albeit small) spillovers in the long run.

3.2.3 *Adjustment at the Extensive Margin*

Further doubts on the common view of international transmission of technology shocks are raised by the recent macroeconomic literature on firm dynamics and endogenous goods variety, which allows for firms' adjustment at both the intensive margin (that is changing the scale of production of a given set of goods) and the extensive margin (via the introduction of new goods).[10] If the firms in a country take advantage of the technological progress of changing the attributes of the goods they produce—the argument goes—productivity gains are not necessarily associated with a fall in the international price of their output.

Developments of this idea developed in a general equilibrium setting can be found in recent papers studying economies where goods variety varies endogenously in response to shocks. Specifically, the international business cycle model by Ghironi and Melitz (2005) predicts that the terms of trade appreciate in response to an increase in (labor) productivity—which reduces symmetrically both in the marginal costs of producing goods, and the sunk cost of setting up new firms. Corsetti, Martin, and Pesenti (2007) show that, under incomplete markets, the terms of trade appreciate in response to productivity gains reducing entry costs, but depreciate if technology innovations make good manufacturing cheaper. Cross-country evidence consistent with these effects is provided by Acemoglu and Ventura (2003) as well as by Debaere and Lee (2004).[11]

A relevant policy issue raised by this class of model is that when the supply of goods varieties is endogenous, international spillovers depend not only on the movements of the terms of trade (an appreciation hurts foreign consumers), but also on the welfare implications of a changing array of goods available to consumers (an increase in varieties benefits foreign consumers). International welfare effects are not directly related to relative price movements: if the consumers love for goods variety is high enough, international spillovers of productivity shocks may be positive even when the terms of trade move against the foreign country.

3.3 Estimating the Effects of a Permanent Technology Shock to Manufacturing

In this section, we present our strategy for identifying the effects of permanent shocks to technology in the manufacturing sector for the United States, Japan, Germany, the United Kingdom, and Italy, in comparison with an aggregate of the other G7 countries and three other OECD countries (Australia, Sweden, and Ireland) for which we were able to obtain quarterly data on hourly labor productivity. We focus on time series evidence and use VAR methods, extending work by Galí (1999), Francis and Ramey (2005), and Christiano, Eichenbaum, and Vigfusson (2004)—where technology shocks are identified via long-run restrictions—to an open economy context. Namely, we adopt the identifying assumption that the only type of shock which affects the long-run level of average labor productivity in manufacturing is a permanent shock to technology. Our work is, therefore, related to a number of recent contributions, which have investigated the effects of technology shocks identified using long-run restrictions in a closed economy framework. This literature uses the basic insight from the stochastic growth model, that only technology shocks should have a permanent effect on labor productivity, to identify economy-wide technology shocks in the data.[12]

As discussed below, we use reduced-form time series methods in conjunction with our identifying assumption in order to estimate the effects of a permanent shock to technology. As argued by Christiano, Eichenbaum, and Vigfusson (2004), an advantage of this approach is that we do not need to resort to the set of assumptions usually required to construct measures of technology shocks based on Solow residuals, including corrections for labor hoarding, capital utilization, and time-varying markups.[13] On the other hand, we are fully aware there exist models in which our identifying assumption may not be verified. An obvious instance is the case of endogenous growth models, where all shocks affect productivity in the long run. Another possibility is that of an otherwise standard two sector model, when there are permanent shocks in both the manufacturing and the other (nontradable goods) sector. To be as sure as possible that we have actually identified technology shocks in the manufacturing sector, our baseline specification includes the relative price of manufactured goods in terms of consumer services, as a proxy for the relative price of domestic tradables in terms of nontradables. This price should fall in response to a technology shock that is specific to the tradable sector.[14]

We examine the effects of technology shocks to the manufacturing sector (our proxy for traded goods), identified with long-run restrictions, on the real exchange rate, the terms of trade, net exports, and relative consumption and output—a detailed description of the data sources is in the data appendix. Over the period 1973 to 2004, we estimate several specifications of the following structural VAR model:

$$\begin{bmatrix} \Delta x_{j,t} \\ \Delta y_t \end{bmatrix} = \begin{bmatrix} C^{xz}(L) & C^{xm}(L) \\ C^{yz}(L) & C^{ym}(L) \end{bmatrix} \begin{bmatrix} \varepsilon^z_{jt} \\ \varepsilon^m_{jt} \end{bmatrix}. \tag{1}$$

Here $x_{j,t}$ denotes the variable that is assumed to respond (in the long run) exclusively to permanent technology shocks; in all our specifications, this variable is the (log of the) quarterly labor productivity in manufacturing, measured in deviation from quarterly labor productivity in manufacturing in the rest of the world (ROW). All ROWs variables are specific to country j and built as an aggregate of a large sample of other countries (excluding country j), weighted according to their respective (time varying) gross domestic product (GDP) shares at purchasing power parity (PPP) values.[15] This set of countries comprises six of the G7 countries (thus including Canada and France), plus Australia, Ireland, and Sweden.[16] The vector $y_{j,t}$ is 5x1, and always includes (the log of) a country specific index of manufacturing production and aggregate consumption relative to the same variable for the ROW, the country's ratio of nominal net export over GDP, and (the log of) the relative domestic producer price index over the domestic consumer price index (of services, when available) in country j. The last variable in $y_{j,t}$ is a measure of international relative prices vis-à-vis the ROW:

$$RER_i = \frac{P_i}{SP_i^*}.$$

where the price indexes P_i and P_i^* are alternatively (the log) of the CPI, PPI, and export deflator; and SP_i^* is also built as a PPP GDP-weighted aggregate of the countries included in the ROW.[17]

Finally, C (L) is a polynomial in the lag operator, ε_{jt}^z denotes the technology shock to manufacturing specific to country j, and ε_{jt}^m represents the other structural, non technology shocks. Although not necessary for identification, implicit in our benchmark specification is the assumption that all the variables other than productivity also have a unit root. Lacking any strong theoretical a priori on the stationarity of the variables included in the VARs, we resorted to standard unit root tests. In our sample, the assumption of nonstationarity is consistently not rejected in the data, but for Japanese net exports test results are shown in tables 3.1 through 3.5.[18] However, following the suggestions in Christiano, Eichenbaum, and Vigfusson (2004), whenever there is some evidence against a unit root, we also estimate specifications of the VARs with the corresponding variable (such as the real exchange rates or net exports) in levels, rather than growth rates.

Together with the usual assumption that the structural shocks ε_t are uncorrelated and have unitary variance, positing $C^{xm}(1) = 0$ is enough to identify ε_t^z. This restricts the unit root in the variable x_t to originate solely in the technology shock. In practice, in order to estimate impulse responses to the technology shock we follow the Bayesian approach for just identified systems discussed in Doan (1992). For each country, we begin by estimating the following fourth-order reduced form VAR:

Table 3.1
Results of Unit Root Tests for USA Against ROW

	Test specification for differenced series PP*		Test specification for level series DF-GLS**	
	test statistic	p-value***	test statistic	p-value***
Labor productivity in manufacturing				
USA	constant	2.7669	1.00 constant, linear trend	0.008538 pvalue>0.1
ROW	constant	–0.7540	0.83 constant, linear trend	–2.280369 pvalue>0.1
Differential	constant	–1.6774	0.44 constant, linear trend	–0.824595 pvalue>0.1
	none	0.0962	0.71 constant	–0.941589 pvalue>0.1
Output differential	constant	0.1959	0.97 constant, linear trend	–1.407352 pvalue>0.1
	none	1.8321	0.98 constant	0.917944 pvalue>0.1
Consumption differential	constant	1.2960	1.00 constant, linear trend	–0.262079 pvalue>0.1
	none	2.0439	0.99 constant	2.798769 pvalue>0.1
Net exports over GDP	none	0.0842	0.73 constant	–0.087946 pvalue>0.0
	constant	1.0842	0.93 constant, linear trend	0.912054 pvalue>0.1
PPI/CPI				
CPI SERVICES	constant	0.674595	0.9912 constant, linear trend	1.064373 pvalue>0.1
Int. relative prices				
RER CPI	none	–0.4388	0.52 constant	–1.356705 pvalue>0.1
	constant	–2.4182	0.14 constant, linear trend	–2.059058 pvalue>0.1
RER PPI	none	–0.8923	0.33 constant	–2.142593 pvalue>0.05
	constant	–2.3484	0.16 constant, linear trend	–2.625866 pvalue>0.1
EXP DEF	none	–0.0055	0.68 constant	–0.327176 pvalue>0.1
	constant	–1.6585	0.45 constant, linear trend	–1.761566 pvalue>0.1

Note: Sample is 1973:1–2004:4
*Phillips-Perron test with critical values from MacKinnon (1991, 1996)
**Augmented DF test modified according to Elliot et al. (1996); critical values from MacKinnon (1991, 1996)
***A p-value less than 0.1 (0.05) means that the null of a unit root is rejected at the 10 (5) percent confidence level

Table 3.2
Results of Unit Root Tests for Japan Against ROW

	Test specification for differenced series PP*		Test specification for level series DF-GLS**	
	test statistic	p-value***	test statistic	p-value***
Labor productivity in manufacturing				
Japan	constant	–1.581681	0.489 constant, linear trend	–1.883897 pvalue>0.1
ROW	constant	1.710243	0.9996 constant, linear trend	–0.860656 pvalue>0.1
Differential	constant	–1.536393	0.5121 constant, linear trend	–0.871536 pvalue>0.1
	none	–0.111406	0.6435 constant	–0.890574 pvalue>0.1
Output differential	constant	–0.979977	0.759 constant, linear trend	–0.792318 pvalue>0.1
	none	–0.1599	0.6266 constant	–0.898556 pvalue>0.1
Consumption differential	constant	0.038817	0.9596 constant, linear trend	–0.02179 pvalue>0.1
	none	–0.599213	0.456 constant	–0.544825 pvalue>0.1
Net exports over GDP	none	–1.86411	0.0596 constant	–2.822581 pvalue<0.01
	constant	–2.814488	0.059 constant, linear trend	–3.035634 pvalue<0.05
PPI/CPI				
CPI SERVICES	constant	–1.182787	0.6806 constant, linear trend	1.064373 pvalue>0.1
Int. relative prices				
RER CPI	none	–0.080443	0.654 constant	–0.724922 pvalue>0.1
	constant	–2.445101	0.1316 constant, linear trend	–2.0698 pvalue>0.1
RER PPI	none	–0.659916	0.4295 constant	–1.420449 pvalue>0.1
	constant	–2.506998	0.1162 constant, linear trend	–2.63375 pvalue>0.1
EXP DEF	none	–1.380222	0.155 constant	–1.981002 pvalue<0.05
	constant	–2.217913	0.201 constant, linear trend	–2.431013 pvalue>0.1

Note: Sample is 1973:1–2004:4
*Phillips-Perron test with critical values from MacKinnon (1991, 1996)
**Augmented DF test modified according to Elliot et al. (1996); critical values from MacKinnon (1991, 1996)
***A p-value less than 0.1 (0.05) means that the null of a unit root is rejected at the 10 (5) percent confidence level

Table 3.3
Results of Unit Root Tests for Germany Against ROW

	Test specification for differenced series PP*		Test specification for level series DF-GLS**	
	test statistic	p-value***	test statistic	p-value***
Labor productivity in manufacturing				
Germany	constant	0.174953	0.97 constant, linear trend	–1.532099 pvalue>0.1
ROW	constant	1.003887	0.9965 constant, linear trend	–1.820061 pvalue>0.1
Differential	constant	–1.026498	0.7425 constant, linear trend	–1.547087 pvalue>0.1
	none	2.049603	0.9903 constant	0.512553 pvalue>0.1
Output differential	constant	–1.249848	0.6513 constant, linear trend	–2.377607 pvalue>0.1
	none	–1.420197	0.1444 constant	0.220451 pvalue>0.1
Consumption differential	constant	0.413563	0.9829 constant, linear trend	–1.656287 pvalue>0.1
	none	–2.339206	0.0192 constant	2.151105 pvalue>0.1
Net exports over GDP	none	–0.904337	0.3227 constant	–0.133904 pvalue>0.1
	constant	–0.7614	0.8261 constant, linear trend	–1.623257 pvalue>0.1
PPI/CPI				
CPI Total	constant	–0.078896	0.9484 constant, linear trend	–1.659919 pvalue>0.1
Int. relative prices				
RER CPI	none	–1.624913	0.0981 constant	–2.191148 pvalue<0.05
	constant	–2.168403	0.2189 constant, linear trend	–2.272668 pvalue>0.1
RER PPI	none	–1.301696	0.1775 constant	–2.191301 pvalue<0.05
	constant	–2.433337	0.1347 constant, linear trend	–2.346221 pvalue>0.1
EXP DEF	none	–0.350547	0.5569 constant	–1.094891 pvalue>0.1
	constant	–1.884669	0.3386 constant, linear trend	–2.223682 pvalue>0.1

Note: Sample is 1973:1–2004:4
*Phillips-Perron test with critical values from MacKinnon (1991, 1996)
**Augmented DF test modified according to Elliot et al. (1996); critical values from MacKinnon (1991, 1996)
***A p-value less than 0.1 (0.05) means that the null of a unit root is rejected at the 10 (5) percent confidence level

Table 3.4
Results of Unit Root Tests for U.K. Against ROW

	Test specification for difference series PP*		Test specification for level series DF-GLS**	
	test statistic	p-value***	test statistic	p-value***
Labor productivity in manufacturing				
UK	constant	0.630927	0.9901 constant, linear trend	−1.485368 pvalue>0.1
ROW	constant	0.762981	0.9931 constant, linear trend	−2.917834 pvalue<0.1
Differential	constant	−1.814605	0.3721 constant, linear trend	−1.521984 pvalue>0.1
	none	−0.334428	0.563 constant	−1.30747 pvalue>0.1
Output differential	constant	−0.763321	0.8256 constant, linear trend	−2.032963 pvalue>0.1
	none	−0.746914	0.3911 constant	−0.489868 pvalue>0.1
Consumption differential	constant	-2.1273	0.2344 constant, linear trend	−0.927952 pvalue>0.1
	none	-0.298068	0.5766 constant	−0.873383 pvalue>0.1
Net exports over GDP	none	−1.883786	0.0571 constant	−2.182391 pvalue<0.05
	constant	−2.300727	0.1734 constant, linear trend	−2.567268 pvalue>0.10
PPI/CPI				
CPI Total	constant	−0.452297	0.9844 constant, linear trend	−1.020843 pvalue>0.1
Int. relative prices				
RER CPI	none	−1.171089	0.2197 constant	−2.101924 pvalue<0.05
	constant	−2.206316	0.2051 constant, linear trend	−2.897819 pvalue<0.10
RER PPI	none	−0.291671	0.579 constant	−0.501317 pvalue>0.1
	constant	−1.496524	0.5323 constant, linear trend	−2.68954 pvalue>0.1
EXP DEF	none	−0.668291	0.4258 constant	−0.596741 pvalue>0.1
	constant	−1.742741	0.4074 constant, linear trend	−2.622335 pvalue>0.1

Note: Sample is 1973:1–2004:4
*Phillips-Perron test with critical values from MacKinnon (1991, 1996)
**Augmented DF test modified according to Elliot et al. (1996); critical values from MacKinnon (1991, 1996)
***A p-value less than 0.1 (0.05) means that the null of a unit root is rejected at the 10 (5) percent confidence level

Table 3.5
Results of Unit Root Tests for Italy Against ROW

	Test specification for difference series PP*		Test specification for level series DF-GLS**	
	test statistic	p-value***	test statistic	p-value***
Labor productivity in manufacturing				
Italy	constant	–2.204301	0.2059 constant, linear trend	–0.883729 pvalue>0.1
ROW	constant	1.594922	0.9995 constant, linear trend	–1.013203 pvalue>0.1
Differential	constant	0.395478	0.9821 constant, linear trend	–0.03336 pvalue>0.1
	none	–0.761495	0.3846 constant	–0.25524 pvalue>0.1
Output differential	constant	–0.181216	0.9367 constant, linear trend	–1.328729 pvalue>0.1
	none	–0.93902	0.3082 constant	–0.677483 pvalue>0.1
Consumption differential	constant	0.036218	0.9594 constant, linear trend	–1.038549 pvalue>0.1
	none	–0.922371	0.3151 constant	–0.151934 pvalue>0.1
Net exports over GDP	none	–2.455012	0.0142 constant	–2.486968 pvalue<0.05
	constant	–2.575099	0.1008 constant, linear trend	–2.844862 pvalue<0.10
PPI/CPI				
CPI SERVICES	constant	–0.288019	0.9224 constant, linear trend	–2.10485 pvalue>0.1
Int. relative prices				
RER CPI	none	–1.911597	0.0537 constant	–2.132607 pvalue<0.05
	constant	–2.61669	0.0922 constant, linear trend	–2.548289 pvalue>0.10
RER PPI	none	–1.574812	0.1082 constant	–1.68943 pvalue<0.1
	constant	–2.56929	0.1021 constant, linear trend	–2.378501 pvalue>0.1
EXP DEF	none	0.233667	0.7525 constant	–0.361994 pvalue>0.1
	constant	–0.893053	0.7878 constant, linear trend	–3.129265 pvalue<0.05

Note: Sample is 1973:1–2004:4
*Phillips-Perron test with critical values from MacKinnon (1991, 1996)
**Augmented DF test modified according to Elliot et al. (1996); critical values from MacKinnon (1991, 1996)
***A p-value less than 0.1 (0.05) means that the null of a unit root is rejected at the 10 (5) percent confidence level

$$Z_{j,t} = \alpha + B_j(L)Z_{j,t-1} + u_{j,t}, Eu_{j,t}u'_{j,t} = \Sigma_j, \quad (2)$$

where

$$Z_{j,t} = \begin{bmatrix} \Delta x_{j,t} \\ \Delta y_{j,t} \end{bmatrix},$$

and u_t is the one-step-ahead forecast error in $Z_{j,t}$. Also, Σ_j is a positive definite matrix. It is well-known that positing a noninformative prior of the normal-Wishart family and a Gaussian likelihood implies that the posterior for parameters of the reduced form VAR above is also normal-Wishart (see Uhlig 2001 for a formal derivation). The parameters, including Σ, can be estimated by ordinary least squares (OLS) applied to each equation. The structural economic shocks (ε_{jt}) are related to u_{jt} by the following relation (dropping the subscript j):

$$u_t = A_0^{-1}\varepsilon_t, E\varepsilon_t\varepsilon_t' = I.$$

As in equation (1), without loss of generality, we suppose that ε_t^z is the first element of ε_t, and $B(L) = A_0^{-1}C(L)^{-1}$. The assumption that $C^{xm}(1) = 0$ implies that the first column of A_0^{-1}, depicting the effects of a technology shock on the variables in the VAR, is uniquely defined by:

$$A_0^{-1} = \tilde{B}(1)[chol(\tilde{B}(1)^{-1}\Sigma\tilde{B}(1)^{-1\prime})]^{-1}, \tilde{B}(1) = [I - B(1)].$$

Therefore, for each draw from the known posterior of the reduced form VAR, we can compute a unique A_0^{-1}, and the associated impulse responses.[19]

3.4 The International Transmission of Permanent Productivity Shocks to Tradables Production

In this and the next section, we report our results for five G7 countries (United States, Japan, Germany, United Kingdom, and Italy) in our sample. Our data are displayed in Appendix A, figures 3A.1–3A.5. We consider the sample period 1973–2004, corresponding to the international monetary system after the collapse of Bretton Woods (and the longest period for which we have data). While we initially included all the G7 countries in our analysis, we were forced to drop France and Canada from the analysis because their unit root tests rejected the hypothesis of nonstationarity in the measure of labor productivity differential with the ROW.[20] In what follows, we report results based on our baseline specification, in which all variables are in growth rates. In the following subsection, we will conduct a sensitivity analysis.

3.4.1 *Baseline Specification*

Figures 3.1 through 3.5 display the impulse response functions for our baseline difference specification, along with 68 percent pointwise poste-

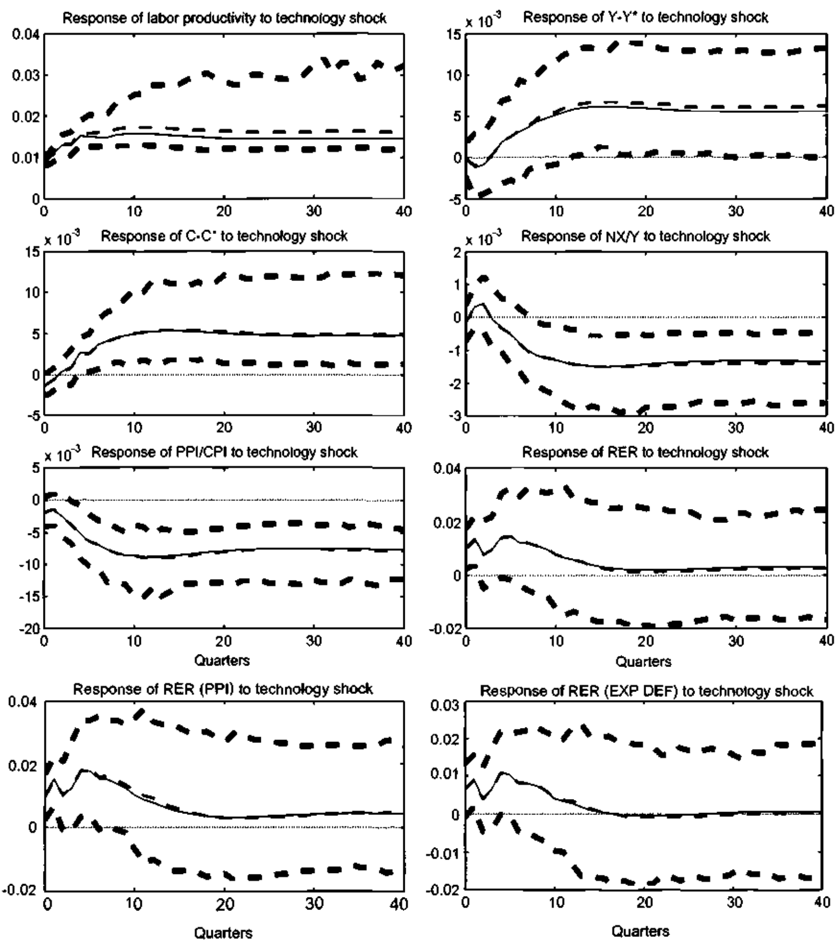

Figure 3.1
Baseline Specification—U.S.
Note: VAR specification with labor productivity differential relative to all other countries, all variables in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

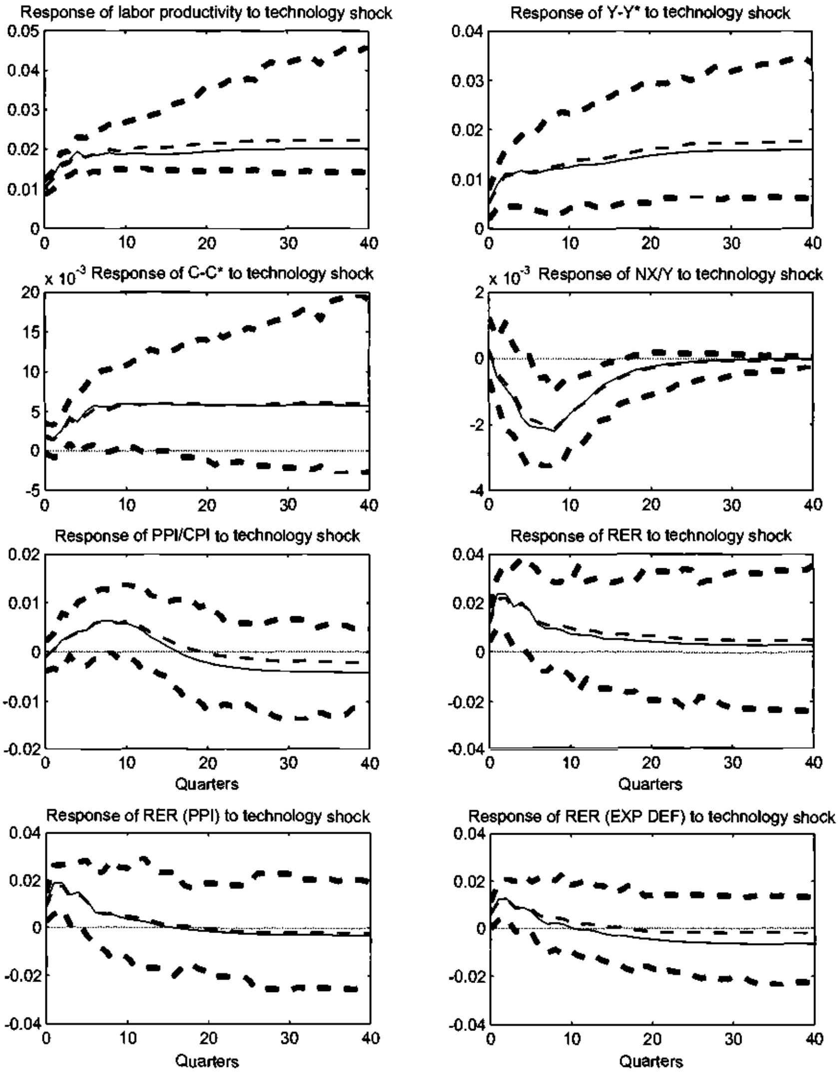

Figure 3.2

Baseline Specification—Japan

Note: VAR specification with labor productivity differential relative to all other countries, all variables but net exports over GDP (NX/Y) in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

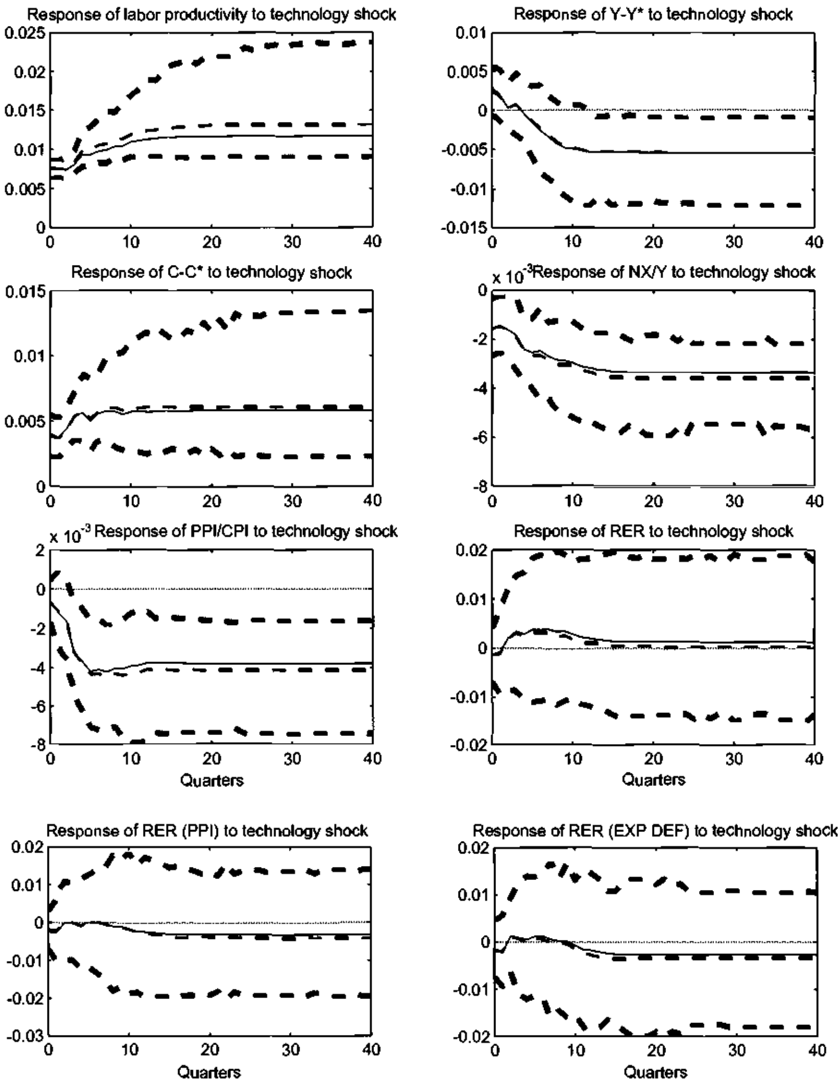

Figure 3.3
Baseline Specification—Germany

Note: VAR specification with labor productivity differential relative to all other countries, all variables in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

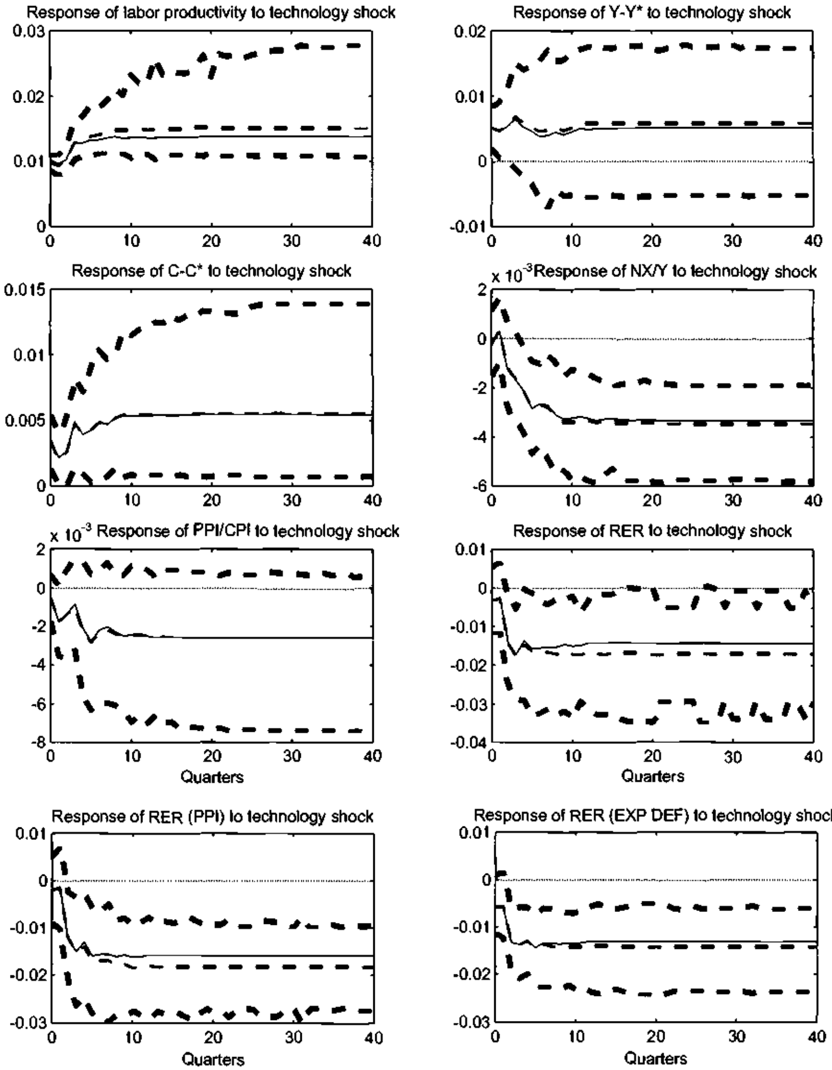

Figure 3.4
Baseline Specification—U.K.

Note: VAR specification with labor productivity differential relative to all other countries, all variables in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

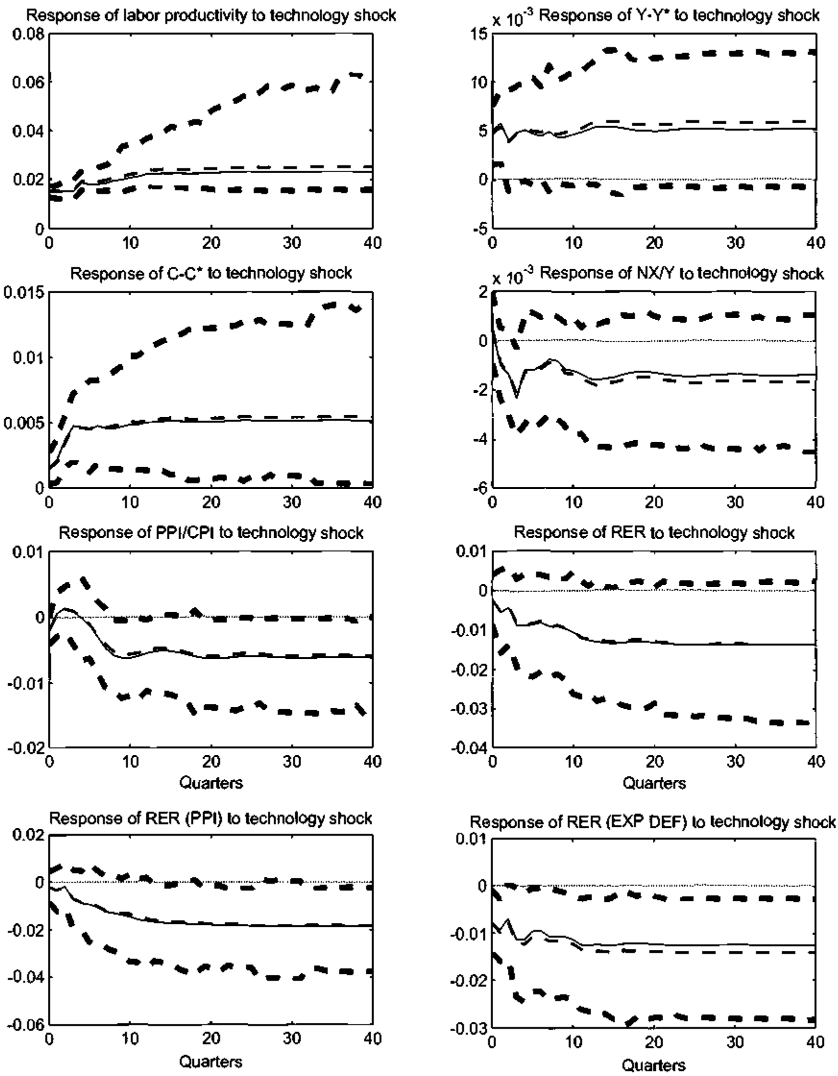

Figure 3.5
Baseline Specification—Italy

Note: VAR specification with labor productivity differential relative to all other countries, all variables in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

rior confidence intervals. For instance, figure 3.1 displays the response of U.S. relative productivity, manufacturing output (Y-Y*), and aggregate consumption (C-C*), (all in log differential with ROW), along with nominal net trade over GDP (NX/Y), the PPI relative to the services CPI, and our three alternative international relative prices (RER), based on the CPI, the PPI and the export deflator. Each figure shows the OLS estimates (the solid line), the median (the thin dashed line), and the 16th and 84th percentiles (the thick dashed lines) of the posterior distribution.

Starting with the United States, the main results are as follows. First, the median impact effect of the shock on relative manufacturing output and aggregate consumption is slightly negative but statistically insignificant in the short run; both variables, however, converge to a permanently higher level after three years. Second, the long-run increase in both these variables is 0.5 percent, against a permanent increase of 1.5 percent in the productivity differential. Note that the rise in relative consumption and productivity are estimated with higher precision than the rise in output. Third, the technology shock leads to a prolonged, statistically significant fall in both net exports and the relative price of domestic tradables. The latter corresponds to a Balassa-Samuelson effect, according to the conventional wisdom about the relative price implications of productivity gains in manufacturing. Note that this result provides some support to the identification scheme underlying our analysis, against the possibility of productivity innovations more concentrated in others sectors (which are less likely to cause a significant increase in the price of nontradables).[21]

The fall in net export may be surprising, in light of some applied and policy literature postulating that a productivity increase in tradables should bring about an improvement in net trade. Against this presumption, our empirical results suggest the deterioration in net trade peaks after about three years (standing at roughly 0.15 percentage points of nominal GDP), and persist in the long-run. While this very persistent effect reflects the assumption—strongly supported by unit root tests—that the net-trade to GDP ratio is nonstationary, it is by no means a mechanical implication of that assumption.[22]

Fourth, the CPI based RER temporarily appreciates (an increase is an appreciation) in the aftermath of the shock, and then goes back to its previous long-run level. Notably, together with the response of relative consumption, the response of the CPI based RER is at odds with the condition for efficient consumption risk sharing—but consistent with the evidence in Backus and Smith (1993). Finally, the other two measures of international relative prices display the same pattern as the CPI based RER. As these two measures are built using PPIs (that is, price indexes including a larger share of tradables than the CPI), and export deflators (including only the price of traded goods), our results suggest that the RER appreciation reflects more than the classical Balassa-Samuelson effect; it also captures important terms of trade effects, as well as deviations from the law of one price (LOP) for manufacturing goods.

In figures 3.2 through 3.5, we report the same set of impulse responses for Japan, Germany, the United Kingdom, and Italy (respectively). Relative to the United States, these countries display similar patterns overall, but also some important differences. For all countries, a positive shock increases the consumption differential after a few quarters, and it decreases both the nominal net trade relative to GDP as well as the relative price of manufacturing in terms of services/overall CPI—with the exception of Japan, where the latter variable initially rises, although insignificantly. The initial positive response of relative manufacturing output translates into a permanent increase in Japan, the United Kingdom, and Italy; however, it is significant only in Japan, where it levels off at around 1.5 percent. Relative output, instead, displays a permanent and significant fall in Germany.[23] Conversely, relative consumption increases permanently in all four countries by around 0.5 percent, albeit insignificantly in Japan. The deterioration of net exports over GDP is stronger in the United Kingdom and Germany, where it is also permanent. In Italy this variable displays a similar qualitative behavior but is significantly negative only for a couple of quarters, one year after the shock. As in the U.S. case, these permanent effects reflect the assumption that the net-trade to GDP ratio is nonstationary, in line with results from unit root tests. In Japan net exports—modelled as stationary—reach a minimum eight to ten quarters after the shock, and then slowly revert to their baseline value. Finally, the relative price of manufactured goods (in terms of services) falls permanently in all countries, although significantly so only in Germany and Italy.

Strikingly different patterns emerge in regards to international pricing. As for the United States, also in Japan, all measures of international relative prices (including the CPI based RER) significantly appreciate in the first few quarters after the shock. Conversely, international relative prices depreciate permanently in the case of Italy and the United Kingdom—for these countries, our results are close to the conventional view of the international transmission mechanism. The response of international prices is small and insignificant in the case of Germany. Note that, as in the United States, for each country in our sample, our three measures of relative prices display the same behavior despite the different weights of tradable goods in the corresponding price indexes. This result lends support to the hypothesis that terms of trade movements and deviations from the law of one price play a crucial role in driving the CPI based real exchange rate dynamics (in the aftermath of the productivity shock).

Our baseline results on the international transmission of productivity shocks to manufacturing can be summarized as follows. First, we find that a positive shock leads to an increase of domestic consumption above foreign consumption, and worsens the trade balance. Second, with the exception of Japan, where this effect turns out to be insignificant, productivity gains (in manufacturing) lower the PPI relative to the (services) CPI. As the latter index includes a much larger share of nontraded goods, this is evidence support the HBS hypothesis (i.e. in response to sector-specific productivity gains, nontraded good prices appreciate relative to tradables).

Third, the real exchange rate response is heterogenous across countries. However, in each individual country our three measures of the real exchange rate move in very similar ways—despite the different degree of tradability of the goods included in the corresponding price indexes (CPI, PPI, or export deflator). In the case of the United States and Japan, productivity gains lead to a short-run appreciation in all our measures of the real exchange rate. In our baseline specification, the response is (instead) not significant for Germany. In the case of the United Kingdom and Italy, we detect permanent depreciations. So, while we find evidence of a Balassa-Samuelson increase in the domestic relative price of nontradables in all countries, the CPI based real exchange rate seem to be driven by a country's terms of trade, as proxied by our export deflator based real exchange rate.[24]

3.4.2 *Sensitivity Analysis*

In this subsection, we investigate the sensitivity of our analysis along three dimensions. First, we allow some variables to enter the VAR specifications in levels, possibly with deterministic trends; second, we verify subsample stability; and third, we reestimate the VAR models with labor productivity growth in each country, not measured in deviations from ROW. Robustness along a further dimension, the choice of variables included in the VARs, was obtained as a by-product of the above analysis (e.g. including a different international relative price, the PPI instead of the CPI based real exchange rate), through alternative specifications of the model. These alternative specifications did not have any significant impact on our results—to save space we do not report them in the text.[25]

Results with Level Specifications It is well-known that VARs with long-run restrictions may be sensitive to mistakenly modeling stationary series as nonstationary because of the ensuing specification error due to overdifferencing (Christiano, Eichenbaum, and Vigfusson 2004). Since unit root tests yield conflicting results regarding the nonstationarity of some of the series, additional VARs were run with these variables in levels, detrending them when appropriate. Note that, by construction, this entails a zero long-run response of these variables. Specifically, the unit root tests give conflicting results for at least one measure of international relative prices in all countries, and for net exports over GDP in the case of the United Kingdom and Italy. This latter variable is stationary in Japan, and nonstationary in the United States and Germany (according to all tests considered).[26]

The results of our sensitivity analysis are reported in figures 3.6 through 3.10, with the same variables' mnemonics and format as before. Namely, each figure shows the OLS estimates (the solid line), the median (the thin dashed line), and the 16th and 84th percentiles (the thick dashed lines) of the pointwise posterior distribution. For the case of United States and Japan, figures 3.6 and 3.7 make it clear that the baseline results are not sensitive to alternative assumptions about the stationarity of international relative prices. In these figures it is assumed that all measures of international prices are stationary around a deterministic trend (as in the case of figures 3.1 and 3.2, all these relative prices appreciate significantly in the short run in response to a positive technology shock).

However, some baseline results turn out to be sensitive to the level specification for Germany, the United Kingdom, and Italy. Although the responses of consumption and output differentials (as well as that of the relative price of nontradables) are generally unchanged, we detect differences in the behavior of international relative prices. Figures 3.8 and 3.9 show that all measures of international relative prices markedly appreciate in the short run in the case of Germany and the United Kingdom. Conversely, the responses of international relative prices in Italy—shown in Figure—turn out to be small and not significantly different

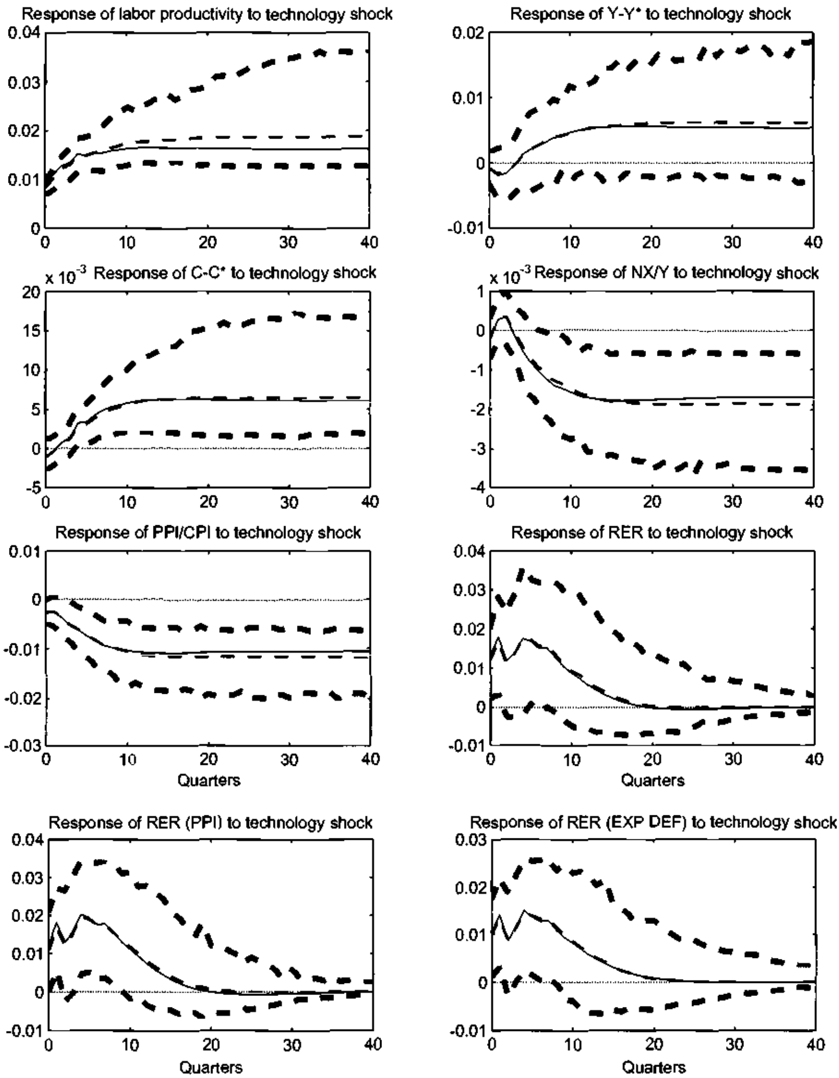

Figure 3.6
Level Specification—U.S.

Note: VAR specification with labor productivity differential relative to all other countries, all variables but real exchange rates (RER) in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

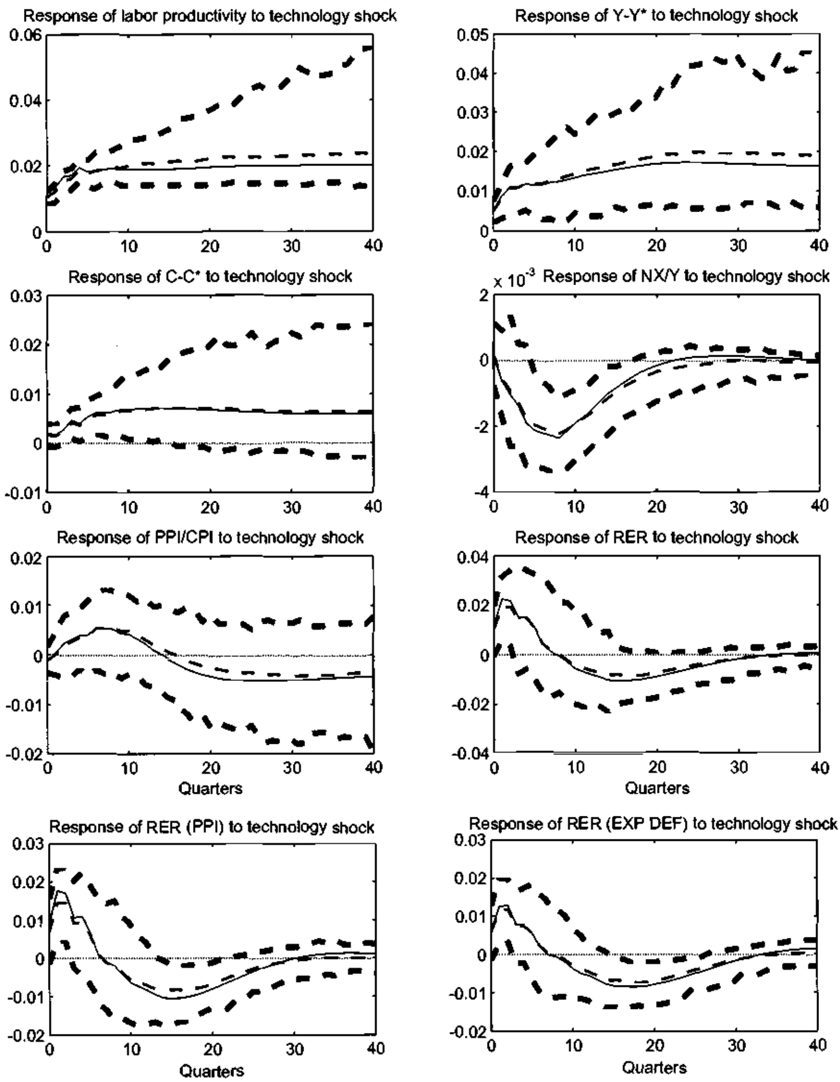

Figure 3.7
Level Specification—Japan

Note: VAR specification with labor productivity differential relative to all other countries, all variables but real exchange rates (RER) and net exports over GDP (NX/Y) in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

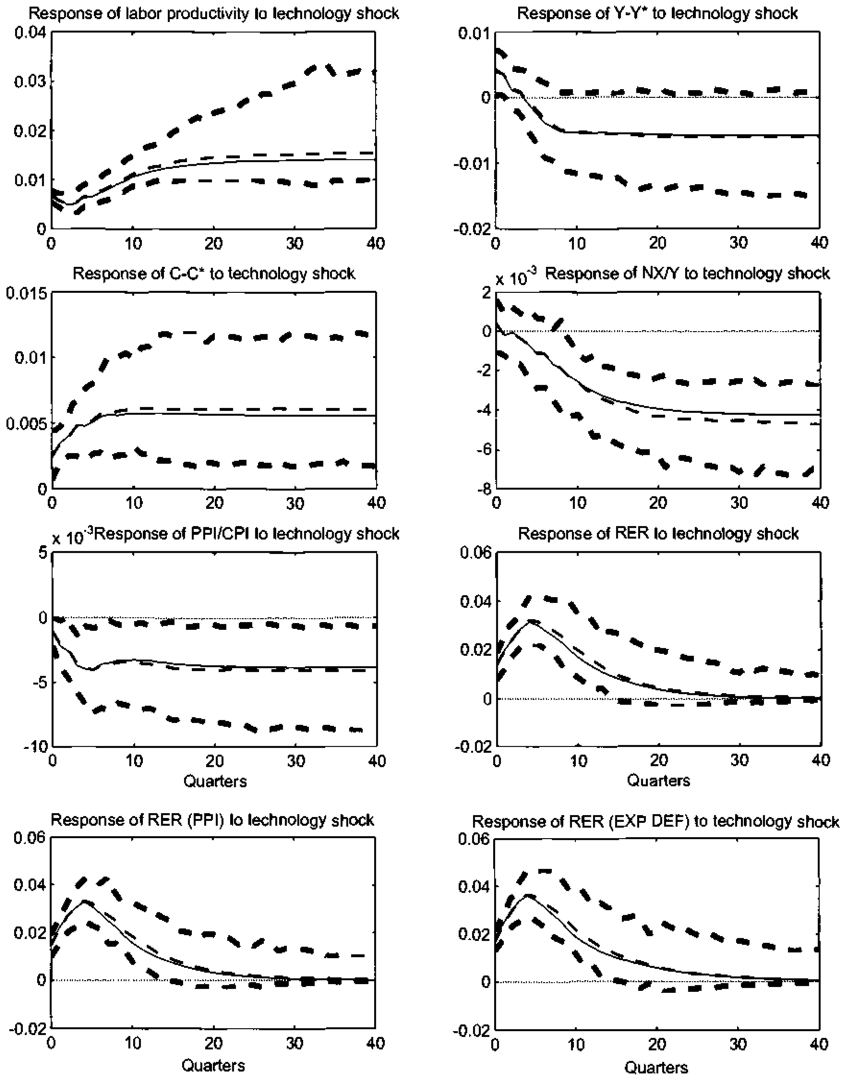

Figure 3.8

Level Specification—Germany

Note: VAR specification with labor productivity differential relative to all other countries, all variables but real exchange rates (RER) in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

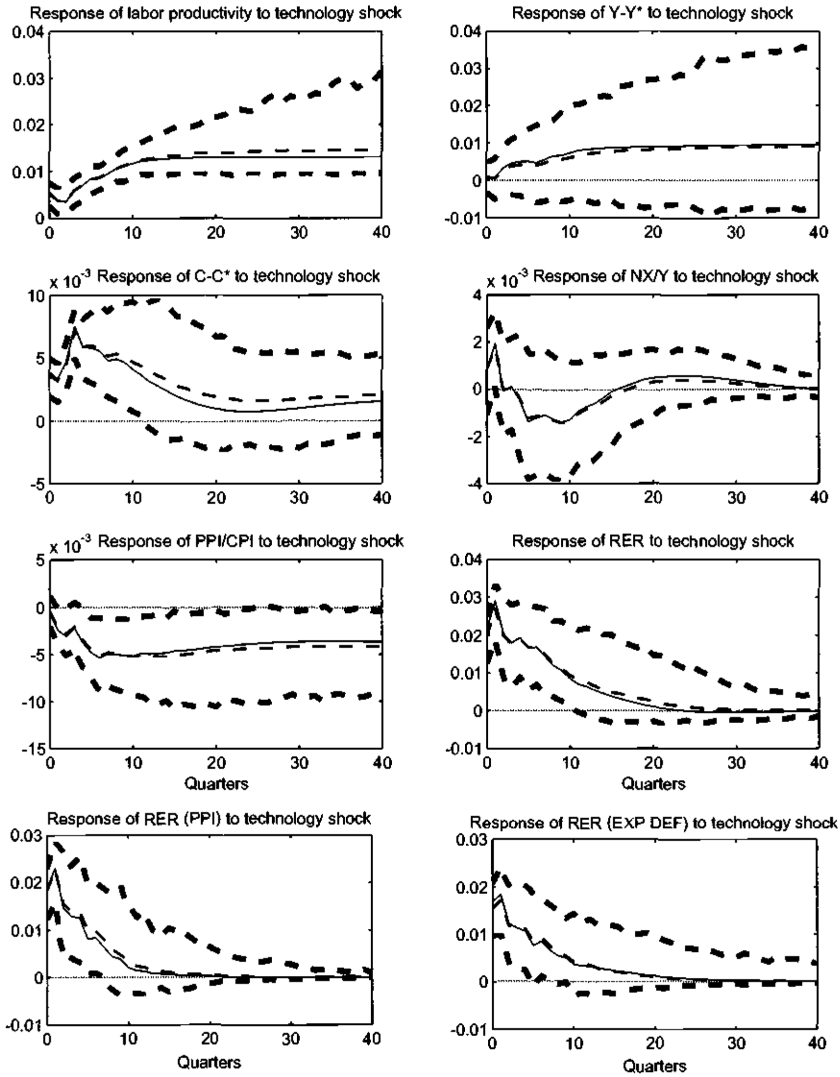

Figure 3.9
Level Specification—U.K.

Note: VAR specification with labor productivity differential relative to all other countries, all variables but real exchange rates (RER) and net exports over GDP (NX/Y) in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

from zero. Finally, modelling net exports in levels for the United Kingdom (figure 3.9) or Italy (figure 3.10) does not change the sign of their responses, as they continue to deteriorate after a few quarters, albeit not significantly.[27]

These results robustly suggest that the international transmission of productivity shocks is at odds with the conventional wisdom—that higher supply leads to terms of trade depreciation—in the cases of the United States and Japan. This conventional wisdom is instead verified for Italy—although the response of the international prices and net exports may be small. For Germany and the United Kingdom, results vary depending on the assumptions about stationarity of the real exchange rate.

Subsample Stability In this subsection we briefly discuss subsample stability, focusing on the benchmark specification. Stock and Watson (2005), among others, have argued that the world economy has become less volatile after the 1970s—commonly referred to as the great moderation—and that this resulted in a structural change in VARs. Moreover, one can observe that the first years in our sample were characterized by the transition from the Bretton Woods regime of fixed exchange rates, to the current regime of floating rates. Finally, the beginning of the twenty-first century has witnessed several changes in the global economy, with the rapid growth of large emerging market countries such as China and India, the launch of the European common currency, and the emergence of large current account imbalances across the world. This subsection assesses the robustness of our conclusions with the possibility of subsample instability due to these changes.

Panels A and B of figure 3.11 display the estimated impulse responses of the variables in our baseline system, for the pre-1999Q1 and post-1978Q4 sample periods, respectively. As before, each figure shows the OLS estimates (the solid line), the median (the thin dashed line), and the 16th and 84th percentiles (the thick dashed lines) of the pointwise distribution in the indicated subsample. To save space, the results for the other countries, are not shown as these substantially confirm the findings for the United States.

The key results are as follows. First, the qualitative patterns of all variables responses are broadly similar across periods, and in full accord to the estimates for the full sample. The U.S. net exports deteriorate persistently, and international relative prices appreciate on impact in both subsamples. Second, both the median and OLS estimates for each sample period would lie well within the 68 percent confidence intervals

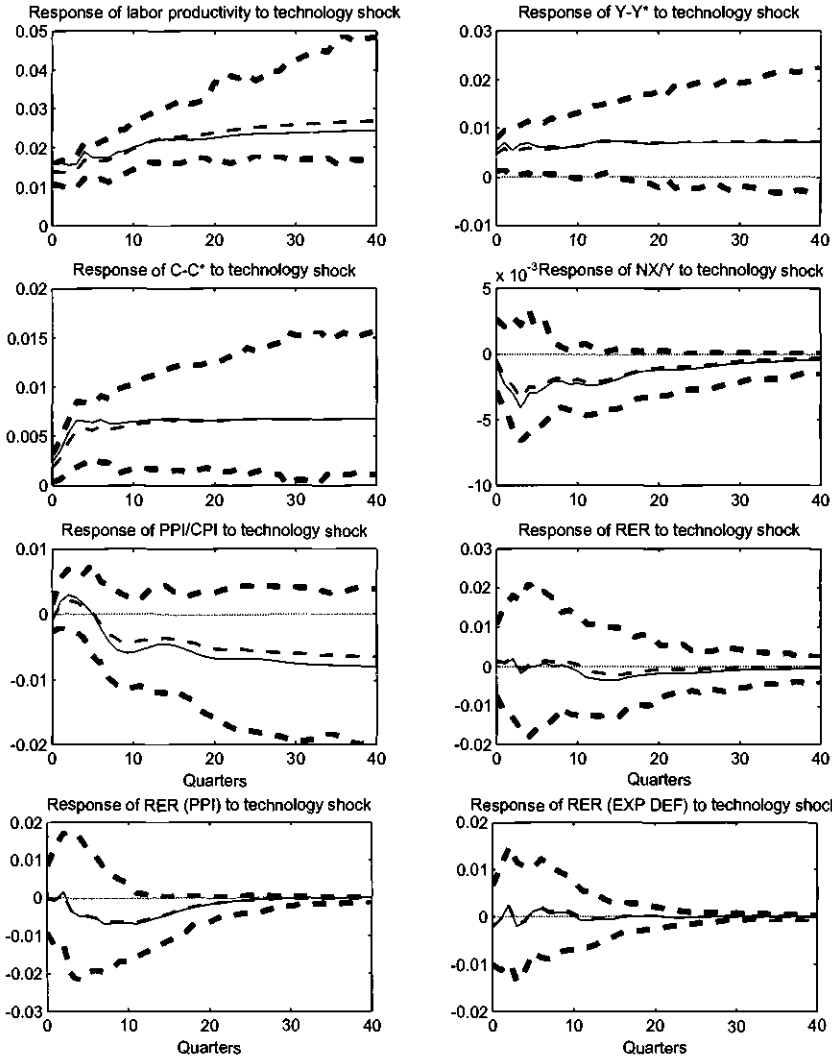

Figure 3.10
Level Specification—Italy

Note: VAR specification with labor productivity differential relative to all other countries, all variables but real exchange rates (RER) and net exports over GDP (NX/Y) in growth rates. The figure reports 16th, median, 84th percentiles and average response. See text for details.

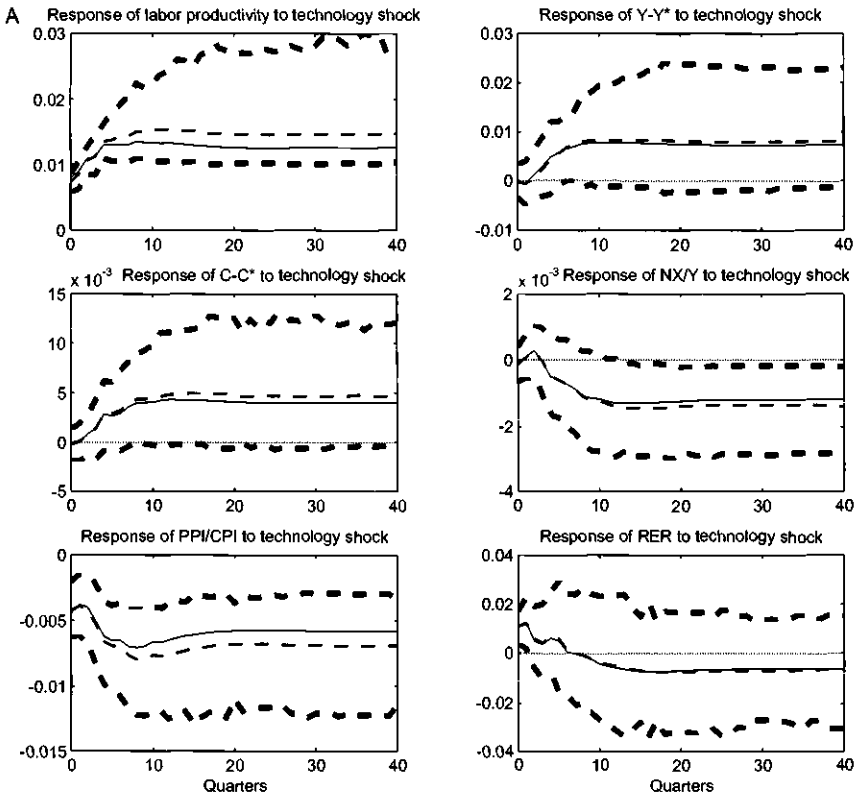

Figure 3.11
Subsample Stability—U.S. Panel A: 1973–1998, Panel B: 1979–2004

Note: VAR specification with labor productivity differential relative to all other countries, all variables in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

in the full sample. This is consistent with the view that the responses in the subperiods are the same as they are for the full sample. However, the estimated effects of technology appear somehow less significant, perhaps due to the loss of degrees of freedom entailed by reducing the number of observations. Overall, this evidence is consistent with the view that the responses in the subperiods are the same as they are for the full sample and there is no break in the international transmission of tradable technology shocks.

Absolute versus Relative Productivity Shocks This section is concluded by briefly discussing what happens if permanent shocks to the ab-

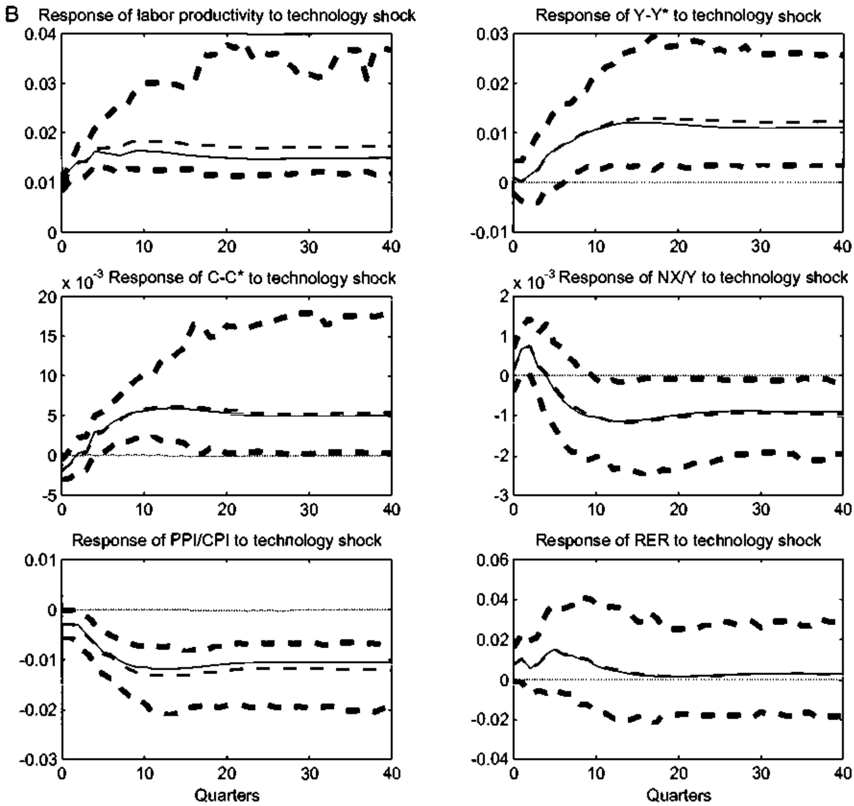

Figure 3.11
Continued

solute level of a country's labor productivity, rather than to its productivity differential relative to the rest of the world is identified. The important difference is that the former shock can diffuse to productivity levels in other countries in the long-run. This is done despite the empirical findings that labor productivity differentials are non stationary—a result in line with the Ricardian idea of perfect specialization in tradables, entertained in most standard DSGE open economy models. These findings notwithstanding, it could be argued that technological diffusion should bring all countries on the same production frontier in the long run. If this view is correct, long-run differentials in measured productivity should be attributed to factors other than technology, e.g. taxes. In this respect, it is worth noting that the closed economy literature from which we borrow our identification strategy is concerned only with shocks affecting the absolute level of productivity in a specific country. In what follows, the robustness of the conclusions to the possibility of misspecification, due to defining productivity in deviations from other countries is assessed.

Figure 3.12 displays the estimated impulse responses of the variables in the system in first differences, where the only departure from the baseline specification above is that labor productivity in the rest of the world is not subtracted from its U.S. counterpart. In accordance with the international focus of the analysis, the other variables are defined exactly as before. As in the previous figures, each chart shows the OLS estimates (the solid line), the median (the thin dashed line), and the 16th and 84th percentiles (the thick dashed lines) of the pointwise distribution in the subsample. As the results for all the other countries substantially confirm our findings for the United States, to save on space, only the results for this country are shown.

The key results are as follows. First, the qualitative and quantitative patterns of all variables responses are in full accord with the baseline estimates in figure 3.1. Relative output and consumption display a permanent increase, while U.S. net exports deteriorate persistently, and international relative prices significantly appreciate in the first few quarters; the PPI falls permanently in terms of CPI services. Second, both the median and OLS estimates would lie well within the 68 percent confidence intervals in the baseline specification in figure 3.1. This is consistent with the view that the responses are the same as for the specifications with productivity differentials, and that the analysis truly identifies shocks that permanently affect U.S. productivity both in absolute level, and relative to the rest of the world.[28]

3.5 Do Identified Impulse Responses Correctly Reproduce the International Transmission?

This section examines whether the identification strategy presented to is able to detect the true effect of a positive technology shock on the terms of trade and the real exchange rate, when this effect can be either an appreciation or a depreciation. We pursue this goal by drawing on recent VAR literature, where the aim is to assess the ability of a given set of identifying restrictions to recover the true impulse responses (when applied to data simulated using stochastic general equilibrium models).[29] In line with this literature, the following experiment is run. First, the time series is simulated from a standard DSGE model with traded and non traded goods similar to that of Stockman and Tesar (1995), except

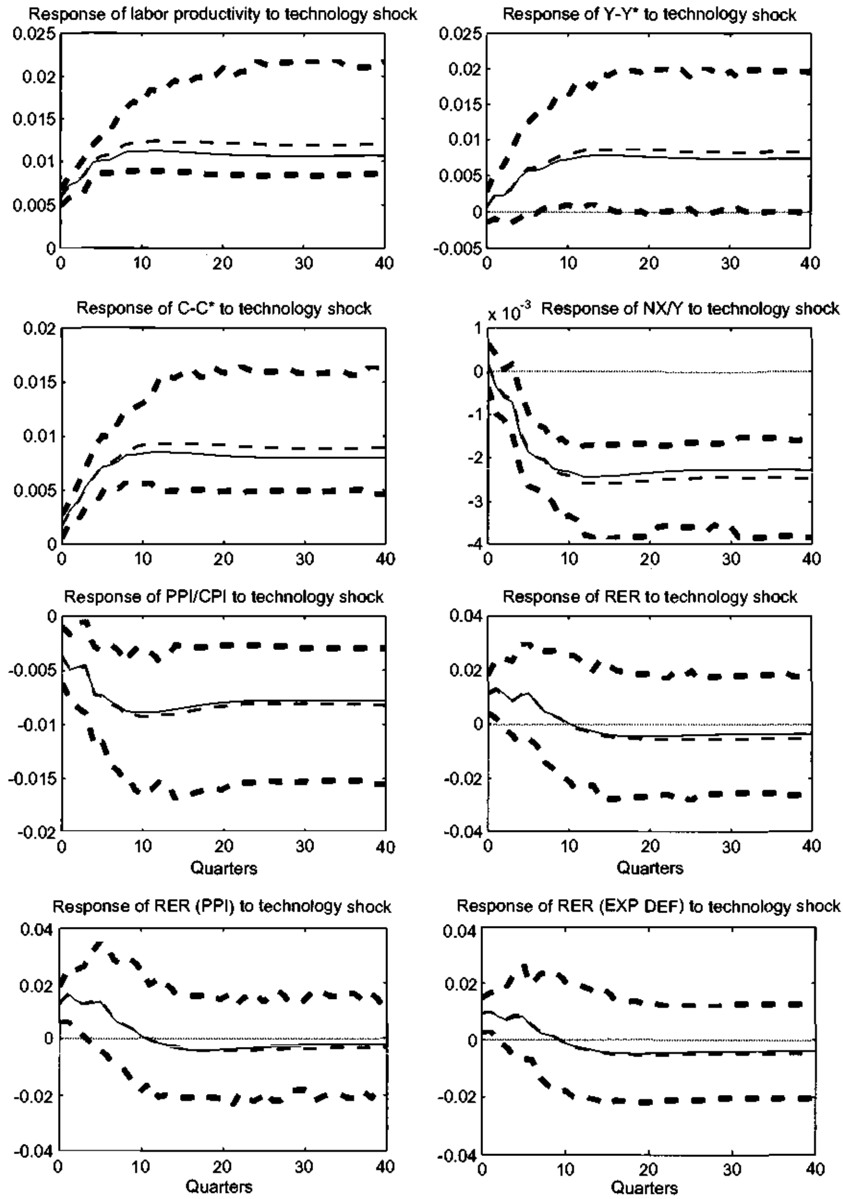

Figure 3.12
Absolute Specification—U.S.

Note: VAR specification with country's level of labor productivity, all variables in growth rates. The figure reports 16th, median, 84th percentiles, and average response.

here incomplete asset markets is assumed. Second, for each realized set of time series, a reduced form VAR with four lags (with the same variables as the baseline specification in section 4), is estimated and then apply the identification scheme (described in section 3) to estimate the effects of technology shocks.

The aim of this exercise is not to provide a broad assessment of the general properties of long-run restrictions with simulated data from models which are estimated from actual macroeconomic data—thus giving a complete description of the latter (Christiano, Eichenbaum, and Vigfusson [2006]). Such an ambitious goal is clearly beyond the scope of this chapter. The question is whether the set of the model's conditional moments (impulse responses) computed by applying VARs with long-run restrictions to simulated data does a good job in detecting different patterns of the international transmission, when simulated data are produced by calibrated open economy models which satisfy the identifying assumption that labor productivity in manufacturing has a unit root because of a nonstationary technology shock. In particular, whether the VARs impulse responses change in the same way as the theoretical impulse responses across models entailing different transmission mechanisms is of particular interest here. This is a prerequisite for impulse responses from identified VARs from the data to be useful in providing guidance in choosing across different open economy models.

The artificial economies used are characterized by home bias in domestic spending on tradables and by the presence of distribution services produced with the intensive use of local inputs; the models, therefore, generate realistic departures from purchasing power parity. The main building blocks of the model are described in Appendix 2, and a more detailed analysis of the model's properties can be found in Corsetti, Dedola, and Leduc (forthcoming). As discussed in section 3.2, the international transmission of productivity shocks to tradables—especially the response of the terms of trade and the exchange rates—can vary significantly, depending on shock persistence and price elasticities. To be consistent with the identification procedure, it is assumed that productivity shocks to tradables follow a unit root process in all experiments. Then the model is simulated under two alternative parameterizations of the trade elasticities, giving rise to different transmission mechanisms of technology shocks to tradables. Namely, the trade elasticities are set equal to one and four respectively. The value of one entails a transmission consistent with the conventional view described in section 3.2.1, and is quite common in contributions subscribing to that view

(Obstfeld and Rogoff 2000). The second, higher value for the trade elasticity (equal to four), is in line with the estimates typically used by international trade studies; with this value, the international transmission follows the pattern described within section 3.2.2. The values of all the other parameters of the model are constant across experiments; Appendix B describes the models calibration in detail. In order to avoid stochastic singularity problems when estimating the VARs, in the simulations other shocks hitting the economy are added, namely persistent shocks to productivity in the nontradable sector in each country and taste shocks to the utility function, as in Stockman and Tesar (1995). All shocks' innovations have the same standard deviation, set to 0.7 percent.

We simulate 100 datasets of 128 time periods for our two alternative parameterizations. As in our empirical VARs, each simulated dataset includes the following variables: relative labor productivity and output in the tradable sector, aggregate relative consumption (all in log differential with ROW, namely the other country), net trade over GDP and the relative price of tradables over nontradables, and the terms of trade (the relative price of exports in terms of imports).

Figures 3.13 and 3.14 report the result from applying long-run restrictions to simulated data from the economy with trade elasticity equal to four and one, respectively. In each chart, we report the theoretical response (the thin dashed line), and the average response estimated by the VAR across all simulations (the solid line). Following Christiano, Eichenbaum, and Vigfusson (2006), we also report two sets of confidence intervals. The first interval, represented by the dashed lines, denotes the true degree of sampling uncertainty (measured by a 68 percent error band around the estimated impulse response functions across the one hundred simulated datasets). The second confidence interval, corresponding to the thick dashed lines, is computed by estimating the VAR and computing confidence intervals for each simulated dataset using the procedure described in section 3.3, and then averaging the upper and lower bands over these one hundred simulations.

Consider first the theoretical responses—the thin dashed lines—under the alternative parameterizations. In both parameterizations, a productivity improvement in the tradable sector leads to a rise in relative labor productivity, relative output, and relative consumption, in order to a fall in the relative price of tradables to nontradables, and to a deterioration of net exports. However, the response of international relative prices differ noticeably across experiments. Because a permanent productivity shock induces sizeable wealth effects that raise home demand

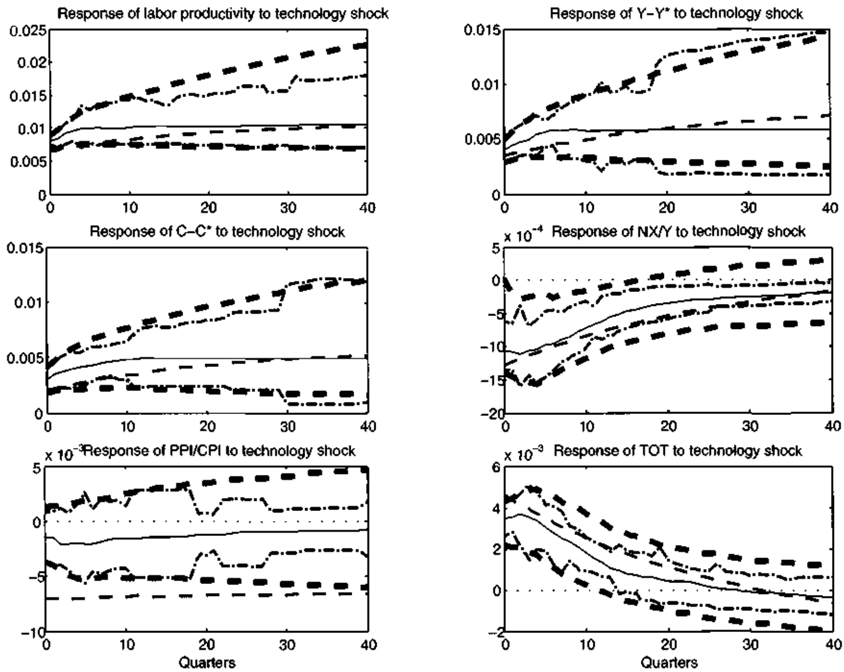

Figure 3.13
Theoretical and VAR Impulse Responses: High Trade Elasticity

for domestic products, the terms of trade persistently appreciate following the shock when the price elasticity is relatively high (figure 3.13)—the real exchange rate, not reported in the figure, moves together with the terms of trade. Conversely, international prices depreciate on impact when the price elasticity is set to one (figure 3.14).

Turning to the estimated impulse responses, it is clear that our identification procedure captures (fairly well) the qualitative features of the different transmission mechanisms. In both parameterizations, the estimated impulse response uncover the correct sign of each variable's response; the VAR average impulse response is in most cases close to the true impulse response. In both experiments, the VAR correctly predicts a permanent increase in relative labor productivity, relative output, and relative consumption. More strikingly, the VAR distinguishes, to a large extent, the differences in the transmission mechanism across experiments. It correctly uncovers an appreciation (depreciation) of the terms of trade in figure 3.13 (and figure 3.14). Notably, in the case of the high trade elasticity, it detects that the appreciation of the terms of trade is

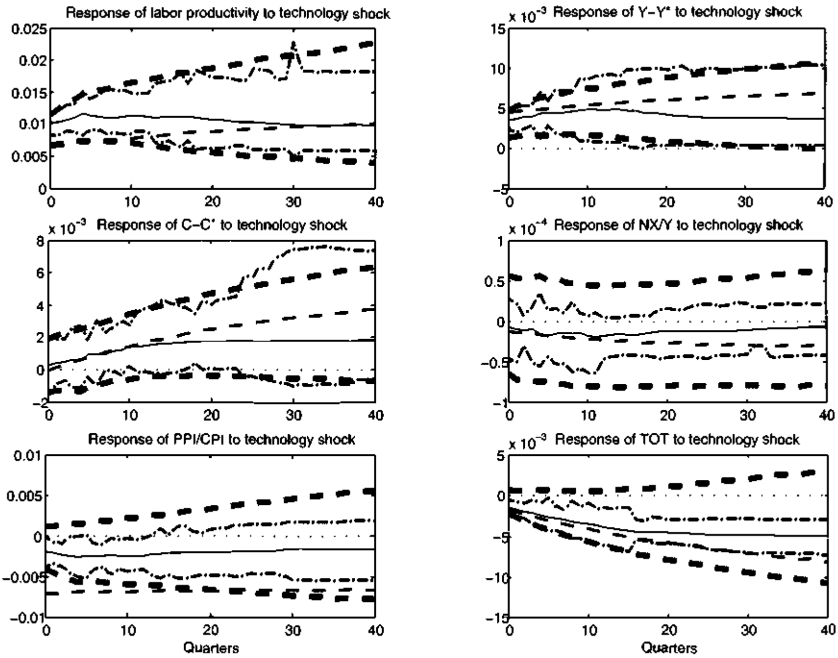

Figure 3.14
Theoretical and VAR Impulse Responses: Unitary Trade Elasticity

persistent but not permanent. However, the VAR has some difficulty uncovering, with precision, the theoretical response of the relative price of nontradables. For this variable, the VAR displays some bias toward zero—this being the only instance in which the true impulse response falls outside of the estimated confidence bands. Finally, note that, as apparent from figures 3.13 and 3.14, the procedure adopted in section 3.3 to compute confidence bands (corresponding to the thick dashed lines), is fairly conservative—as it typically encompasses the true degree of sampling uncertainty (corresponding to the dashed lines). These results, therefore, suggest that an econometrician using our procedure would be unlikely to infer incorrectly that a response is significant when the true response is not.

To sum up, the experiments discussed in this section suggest that, if the identifying assumption that the only source of unit root in labor productivity in manufacturing is correct, the empirical findings are unlikely to be driven by some bias inherent in this approach. This result is viewed as supporting this approach, and the methodology appears to lead to a correct inference of the international transmission of technology shocks to tradables.

3.6 Discussion and Implications for Open-Economy Modeling and Policy Analysis

In this chapter, empirical evidence is provided on the international transmission of productivity shocks among G7 countries. Relative to the literature, this contribution is novel in at least two respects. First, it applies time series methods with minimal identifying assumptions to international data. Second, the dynamics of the international transmission and international relative prices are studied together, distinguishing between the relative price of nontradables, the real exchange rate, and the terms of trade.

The main result is that the international transmission of productivity shocks in manufacturing—identified with the tradable sector—squares well with the main predictions of standard general equilibrium models of the international economy (discussed in section 3.2).

In addition, productivity gains in manufacturing lower the PPI relative to the (services) CPI in all countries. As the latter index includes a much larger share of nontraded goods, this is evidence in support of the Harrod-Balassa-Samuelson hypothesis.

However, the response of international prices is not identical across countries, but appears to vary across economies with different size and degree of openness. Namely, both the real exchange rate and the terms of trade appreciate in the largest and less open economies—the United States and Japan—in contrast with a conventional view of the international transmission. Conversely, international relative prices depreciate in a small open economy such as Italy, but similar results for the United Kingdom turn out to depend on assuming non stationarity of the real exchange rate. Results for Germany are inconclusive.

The results for the United States and Japan challenge a popular view of the core transmission mechanism in DSGE models of the international economy. They suggest that price movements may raise the international consumption risk of productivity fluctuations, as countries with larger supplies will also rip further gains from favorable terms of trade movements; by the same token, the sign of the spillovers from productivity shocks may be negative, with relevant policy implications. Namely, these results help understand the dynamics of the U.S. terms of trade and real exchange rate when this country experienced a persistent increase in productivity growth in the second half of the 1990s—whereas both the relative price of U.S. exports and the U.S. real exchange rate appreciated together. In this respect, the terms of trade dynamics unveiled by our empirical analysis counter the view that favorable price movements contain national wealth differences when countries experience (persistent) productivity growth differentials. In such circumstances, market forces may provide much less automatic stabilization of consumption and real income across borders than commonly believed. Finally, the evidence suggests that terms of trade movements in the short and medium run are the opposite of what is postulated by many observers, (Obstfeld and Rogoff 2004), who build world wide adjustment scenarios following a reduction of the U.S. current account deficit. These measures of the U.S. international price of tradables, instead, appreciate on impact with productivity gains in the U.S. domestic tradable sector.

Third, as a general pattern, positive shocks raise total domestic consumption and manufacturing output, relative to their foreign counterpart, and worsen the trade balance. The negative response of net exports is stronger in the case of the three largest countries; it is insignificant only in some specifications of the empirical model for Italy and the United Kingdom. The finding that the external account response is persistently negative is especially relevant for the case of the United States. These results are at odds with the view expressed in recent policy contributions, that productivity growth in U.S. manufacturing could lead to an early and relevant improvement in the U.S. external trade balance. According to the VAR evidence here, other things equal, the dynamics of domestic demand in response to productivity shocks is not likely to contribute to a U.S. current account reversal (at least in the short and medium run). Instead, these results lend support to the standard policy view that productivity growth in the rest of the (industrial) world could help reduce the U.S. current account deficit, even when relatively concentrated in the production of tradables.

Acknowledgments

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Notes

1. Acemoglu and Ventura (2003) argue that, because of offsetting terms of trade movements, the world distribution of wealth can be stationary even in the absence of technological spillovers (i.e. if technical progress remains confined to a single country).

2. To emphasize this point, Cole and Obstfeld (1991) point out that, with unitary elasticity of substitution between domestic and foreign goods and no home bias, international consumption risk sharing can be achieved without any international trade in assets.

3. We could not include France and Canada in the analysis because of the results of unit root tests on relevant variables (see section 3.4).

4. For instance, the quantitative model in section 3.5 predicts that productivity shocks in the nontradable sector would lead to a real exchange rate and terms of trade depreciation, irrespective of the effects on these variables of shocks to tradables productivity. While these results may vary across model specification, it remains true that (in general) the overall effect of aggregate shocks on external variables is bound to depend on the relative strength and correlation of sectoral shocks.

5. As discussed in the text, this proxy is built because bilateral import and export prices are unavailable for most countries in this sample.

6. While the textbook version of the HBS hypothesis is often phrased in reference to a real appreciation of the exchange rate, this analysis emphasizes that such a version is not correct when countries are specialized in the production of different tradable goods. In this case, whether or not the increase in the relative price of nontradables across countries also transpires into an appreciation of the real exchange rate depends on the sign and relative strength of the terms of trade movement.

7. This result also holds when, in the U.S. VAR model, the terms of trade are specified as the relative price of exports in terms of overall U.S. imports.

8. "We dispel some common misconception about what kind of shifts are needed to help close the U.S. current account imbalances. Faster growth abroad helps only if it is relatively concentrated in nontradable goods; faster productivity growth in foreign tradable goods is more likely to exacerbate the U.S. adjustment problem (Obstfeld and Rogoff 2004, ii)."

9. It is easy to verify that a similar argument also goes through in models without nontradables, but home bias in consumption. In this case, the real exchange rate and the terms of trade move in the same direction. Then, a productivity shock raising domestic consumption cannot but depreciate both international prices.

10. A theoretical attempt to build a model encompassing a discussion of both elasticities and creation of new goods is provided by Ruhl (2003).

11. Also in this class of models, the intensity as well as the direction of international price movements depend on the degree of international consumption risk sharing, as well as on the elasticity of labor supply (Corsetti, Martin and Pesenti 2007).

12. See Shapiro and Watson (1988). Some open economy papers, following Blanchard and Quah (1989), use long-run restrictions derived in the context of the traditional aggregate demand and aggregate supply framework. For instance, Clarida and Galí (1994) identify supply shocks by assuming that demand and monetary shocks do not have long-run effects on relative output levels across countries. While monetary shocks satisfy this assumption in most models, fiscal or preference shocks do not since they can have long-run effects on output (and hours) in the stochastic growth model. A survey of the closed economy literature using long-run restrictions is in Galí and Rabanal (2005).

13. This is the approach followed by Basu, Fernald, and Kimball (2006). For yet another alternative based on sign restrictions, see Dedola and Neri (2007).

14. In Corsetti, Dedola, and Leduc (forthcoming), annual total factor productivity (TFP) data for the U.S. was used to obtain very similar results to those reported below. As argued by Chang and Hong (2002), the use of TFP provides a further check on the identification strategy, as it amounts to controlling for long-run effects on labor productivity brought about by changes in the long-run capital labor ratio by other permanent shocks, e.g. capital tax rate shocks (Uhlig 2003). Unfortunately, the analysis in Corsetti, Dedola, and Leduc (2004) could not extend to the other countries because of lack of data on sectoral TFP.

15. GDP shares are used since trade weights were not available for all countries going back to 1970.

16. These ten countries add up to roughly half of world GDP at PPP values, so they represent a substantial sample of the global economy. Moreover, trade flows among them also amount to over a half of their respective total trade (on average). For instance, the U.S. trade share with the other nine countries in our sample is around 60 percent of U.S. total trade.

17. This is meant to capture the following well-known decomposition of the CPI based real exchange rate between a first component (due to the relative price of tradables across countries) and a second component due to the relative price of tradables in terms of nontradables within countries (see Engel 1999):

$$RER = \frac{P}{SP^*} = \frac{P_T}{SP_T^*}\left(\frac{P_T^*}{P_N^*}\right)\left(\frac{P_N}{P_T}\right).$$

18. Both the Phillips and Perron (1988), and Elliot, Rothenberg, and Stock (1996) general least squares (GLS) modified Dickey-Fuller tests were run, allowing the level of variables to have alternatively a constant term or also a deterministic trend.

19. Results below are based on one thousand draws.

20. Precisely, in the case of France and Canada both the Phillips-Perron and the GLS Dickey-Fuller tests rejected the null of nonstationarity at the 1 and 10 percent confidence level (respectively).

21. Moreover, if the identification scheme was picking just an (offsetting) measurement error in manufacturing labor productivity and the PPI, it would be quite far-fetched that this measurement error be also positively correlated with very persistent increase in relative aggregate consumption and deterioration of net exports.

22. See Engel and Rogers (2005) for further evidence on the nonstationary behavior of U.S. net trade.

23. This result for Germany does not sit well with the assumption that the identified shock is a positive technology shock, although in principle it could be consistent with it in the

presence of large positive wealth effects on domestic labor supply and/or strong complementarity between tradables and nontradables. However, alternative interpretations run into even more serious problems. Similarly, in the case of a measurement error in labor productivity discussed previously, attributing the estimated responses to an increase in labor taxes would be consistent with the output drop which accompanies the productivity increase (but could hardly be reconciled with the positive wealth effect implied by the response of both consumption and net exports). Moreover, such interpretation would also be at odds with the large fall in the domestic relative price of manufactured goods.

24. In their comments, Basu Fernald, and Kimball (2006) present evidence on the response of the U.S. real exchange rate and net exports to a shock to productivity using their carefully constructed productivity measure, which refers to the U.S. economy as a whole. According to these results, the real exchange rate tends to depreciate, and net exports tend to improve (although not significantly so) in response to a positive productivity shock. In view represented in this chapter, this is a very interesting result, which points to the importance of distinguishing between productivity dynamics in different sectors of the economy, and being precise about spillovers and correlation across sectors. Indeed, the theoretical model presented in section 5 predicts that productivity shocks in the nontradable sector have exactly the dynamic effects shown by Basu, Fernald, and Kimball—irrespective of the response to tradables productivity shocks. Their findings are not necessarily in contradiction with the evidence presented here, to the extent that the measure of productivity used in their analysis predominantly captures shock dynamics in the nontraded good sector.

25. Specifications of the model, including other domestic and international variables (like total and nonresidential investment) and aggregate GDP, obtained broadly similar results to those discussed in the text. Additional robustness exercises are provided by Kollmann (1995) in his comments. Although his discussion emphasizes a few cases in which results differ from those presented here, his findings are generally viewed as confirmatory. Mostly, divergences come from simple bivariate specifications of the VAR model including only productivity and one relative price, and from VAR specifications where key variables in the specification, such as relative consumption and net exports, are dropped (to be replaced by other variables, such as the CPI and government spending). These results are not surprising, in light of the classic argument—recently reiterated by Watson (2006)—that in order to recover structural shocks, VARs should include good instruments, that is, variables that are likely to be highly affected by these shocks.

26. For these latter two variables, besides the Phillips-Perron and GLS Dickey-Fuller tests, KPSS tests (Kwiatkowski et al. 1992) were also run. The null of stationarity was rejected at least at the 5 percent level, even when deterministic trend in the variables' level specification was included.

27. A specification for Germany was run with the detrended consumption differential in level, given that the Phillips-Perron test without a constant rejected a unit root in this variable at the 5 percent level. Since results are very similar to those displayed in figure 3.8, they are not reported in this chapter.

28. For the United States, a system with quantity variables not in deviations from the rest of the world is estimated, and terms of trade and real exchange rates defined vis-à-vis a broader set of countries, from the OECD Economic Outlook database, are used. Again broadly similar results are found, compared to those reported in figure 3.12. In addition, the findings are further corroborated by Bems, Dedola, and Smets (forthcoming)—who also find that, in line with the predictions in Backus, Kehoe, and Kydland (1995), shocks that permanently increase U.S. labor productivity in the overall business sector bring

about a deterioration of net trade. Enders and Mueller (2006), also find that these shocks appreciate both the terms of trade, and the real exchange rate.

29. See Erceg, Guerrieri, and Gust (2005); Chari, Kehoe, and McGrattan (2004); Giannone, Reichlin, and Sala (2006); and Christiano, Eichenbaum, and Vigfusson (2006).

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Appendix A Data Description and Sources

United States

Labor productivity: Index of output per hour of all persons in manufacturing sector; seasonally adjusted, 1992 = 100 (Bank of International Settlements and Department of Labor).

Manufacturing output: Index of industrial production in manufacturing; seasonally adjusted, 2000 = 100 (Federal Reserve Board)

Consumption: Private final consumption expenditure, volume in national currency; seasonally adjusted (OECD, Economic Outlook Database).

Nominal GDP: Gross domestic product, value, market prices in national currency; seasonally adjusted (OECD, Economic Outlook Database)

Net exports: Net exports of goods and services, value in national currency; seasonally adjusted (OECD, Economic Outlook Database)

PPI index: Producer price index of manufactured products; seasonally adjusted, 2000 = 100 (OECD, Main Economic Indicators Database)

CPI total: Consumer price index of all items; seasonally adjusted, 2000 = 100 (OECD, Main Economic Indicators Database)

CPI services: Consumer price index for services, less energy services, seasonally adjusted, 1982–84 = 100, monthly converted to quarterly averages (BLS)

Export deflator: Exports of goods and services, deflator; seasonally adjusted, national accounts basis, 2000 = 100 (OECD, Economic Outlook Database)

CPI based real exchange rate: Index of ratio of U.S. CPI (total) to aggregate CPI (total) of nine OECD countries, all in current U.S. dollars; weighted with GDP shares at annual PPP values, 1970Q1 = 100 (authors calculations based on OECD, Economic Outlook Database)

PPI based real exchange rate: Index of ratio of U.S. PPI (manufacturing) to aggregate PPI (manufacturing) of nine OECD countries, all in current U.S. dollars; weighted with GDP shares at annual PPP values, 1971Q1 = 100 (authors calculations based on OECD, Economic Outlook Database)

Terms of trade: Index of ratio of U.S. export deflator (goods and services) to aggregate export deflator (goods and services) of nine OECD countries, all in current US dollars; weighted with GDP shares at annual PPP values, 1970Q1 = 100 (authors calculations based on OECD, Economic Outlook Database)

Japan

Labor productivity: Index of output per hour of all persons in manufacturing; obtained as ratio of industrial production to total hours worked in manufacturing, 2000 = 100 (OECD, Main Economic Indicators).

Manufacturing output: Index of industrial production in manufacturing; seasonally adjusted, 2000 = 100 (Federal Reserve Board)

Consumption: Private final consumption expenditure, volume in national currency; seasonally adjusted (OECD, Economic Outlook Database).

Nominal GDP: Gross domestic product, value, market prices in national currency; seasonally adjusted (OECD, Economic Outlook Database)

Net exports: Net exports of goods and services, value in national currency; seasonally adjusted (OECD, Economic Outlook Database)

PPI index: Producer price index of manufactured products; seasonally adjusted, 2000 = 100 (OECD, Main Economic Indicators Database)

CPI total: Consumer price index of all items; seasonally adjusted, 2000 = 100 (OECD, Main Economic Indicators Database)

CPI services: Consumer price index for services less rents; seasonally adjusted, 2000 = 100 (OECD, Main Economic Indicators Database)

Export deflator: Exports of goods and services, deflator; seasonally adjusted, national accounts basis, 2000 = 100 (OECD, Economic Outlook Database)

CPI based real exchange rate: Index of ratio of Japanese CPI (total) to aggregate CPI (total) of nine OECD countries, all in current U.S. dollars; weighted with GDP shares at annual PPP values, 1970Q1 = 100 (authors calculations based on OECD, Economic Outlook Database)

PPI based real exchange rate: Index of ratio of Japanese PPI (manufacturing) to aggregate PPI (manufacturing) of nine OECD countries, all in current U.S. dollars; weighted with GDP shares at annual PPP values, 1971Q1 = 100 (authors calculations based on OECD, Economic Outlook Database)

Terms of trade: Index of ratio of Japanese export deflator (goods and services) to aggregate export deflator (goods and services) of nine OECD countries, all in current U.S. dollars; weighted with GDP shares at annual PPP values, 1970Q1 = 100 (authors calculations based on OECD, Economic Outlook Database)

Germany

Before 1991, all series were obtained on the basis of West Germany growth rates applied to level variables of unified Germany.

Labor productivity: Monthly index of output per hour of all persons in manufacturing and mining, seasonally adjusted, 2000 = 100 (Bank of International Settlements).

All other series are from the same sources as Japanese series, but for CPI services which is not available.

United Kingdom

Labor productivity: (1) From 1970 to 1995Q1, quarterly index of output per hour of all persons in manufacturing, seasonally adjusted, 1990 = 100 (Bank of International Settlements); (b) from 1995Q1 to 2004Q4, quarterly index of output per person in manufacturing, seasonally adjusted, 2002 = 100 (Bank of International Settlements), divided by the quarterly index of average hours worked per person in manufacturing (from Eurostat). The series were joined by using growth rates over overlapping periods.

All other series were from the same sources as Japanese series, except for CPI services (which was not available).

Italy

Labor productivity: Hourly labor productivity in manufacturing, seasonally adjusted, in 1995 national currency (Bank of International Settlements). A missing value in 1999Q1 was filled by interpolation with output in manufacturing.

All other series were from the same sources as Japanese series, but for

PPI from 1970 to 1980, which is the monthly price index of domestical finished manufactures, 1980 = 100 (BIS). The MEI and BIS monthly series were joined by using growth rates over overlapping periods and then converted by quarterly averaging.

Rest of the world

For each country the rest of the world comprises the other six G7 countries (alternatively United States, Japan, Germany, United Kingdom, Italy, France, and Canada) plus Australia, Sweden, and Ireland. This choice was dictated by data availability regarding hourly productivity in manufacturing.

Individual country's variables were aggregated by first taking quarterly growth rates to remove national basis effects; then cross-country average growth rates were computed with weights based on each country's GDP share in the nine country aggregate calculated at annual purchasing power parity (PPP) values. Average growth rates were then cumulated starting from the initial base year to obtain levels.

Annual PPP based GDP shares are from the International Monetary Funds (IMF) World Economic Outlook Database from 1980; before 1980 they were computed directly on the basis of annual GDP at PPP values form OECDs Economic Outlook Database.

Labor productivity: Aggregate of country-specific indexes of output per hour of all persons in manufacturing sector; seasonally adjusted, 1970Q1 = 100 (authors calculations based on national statistical sources)

Manufacturing output: Aggregate of country-specific indexes of industrial production, manufacturing; seasonally adjusted, 1970Q1 = 100 (authors calculations based on national statistical sources)

Consumption: Aggregate of country-specific private final consumption expenditure, volumes in national currency; seasonally adjusted, 1970Q1 = 100 (authors calculations based on OECD, Economic Outlook Database).

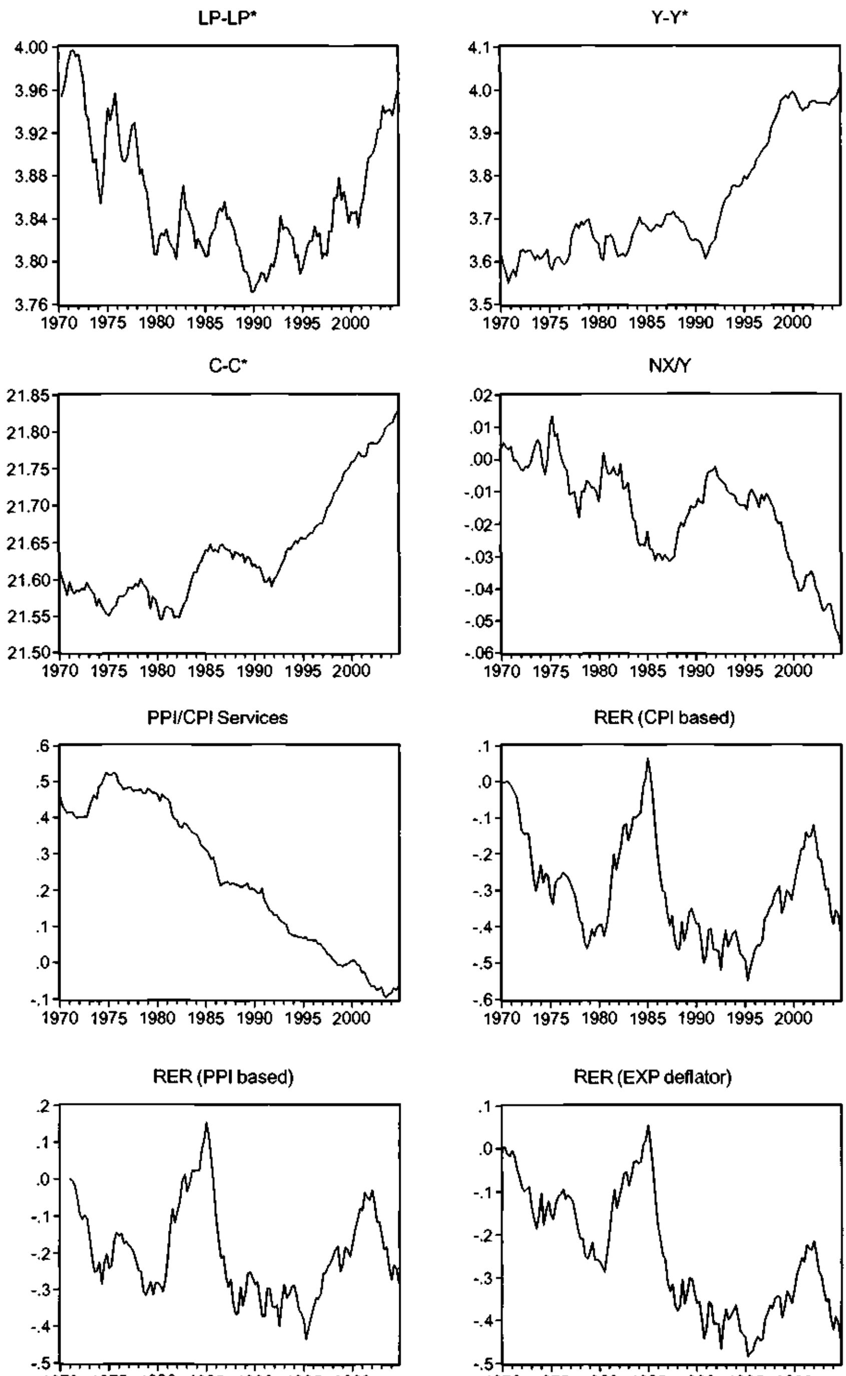

Figure 3A.1
U.S. VAR Data

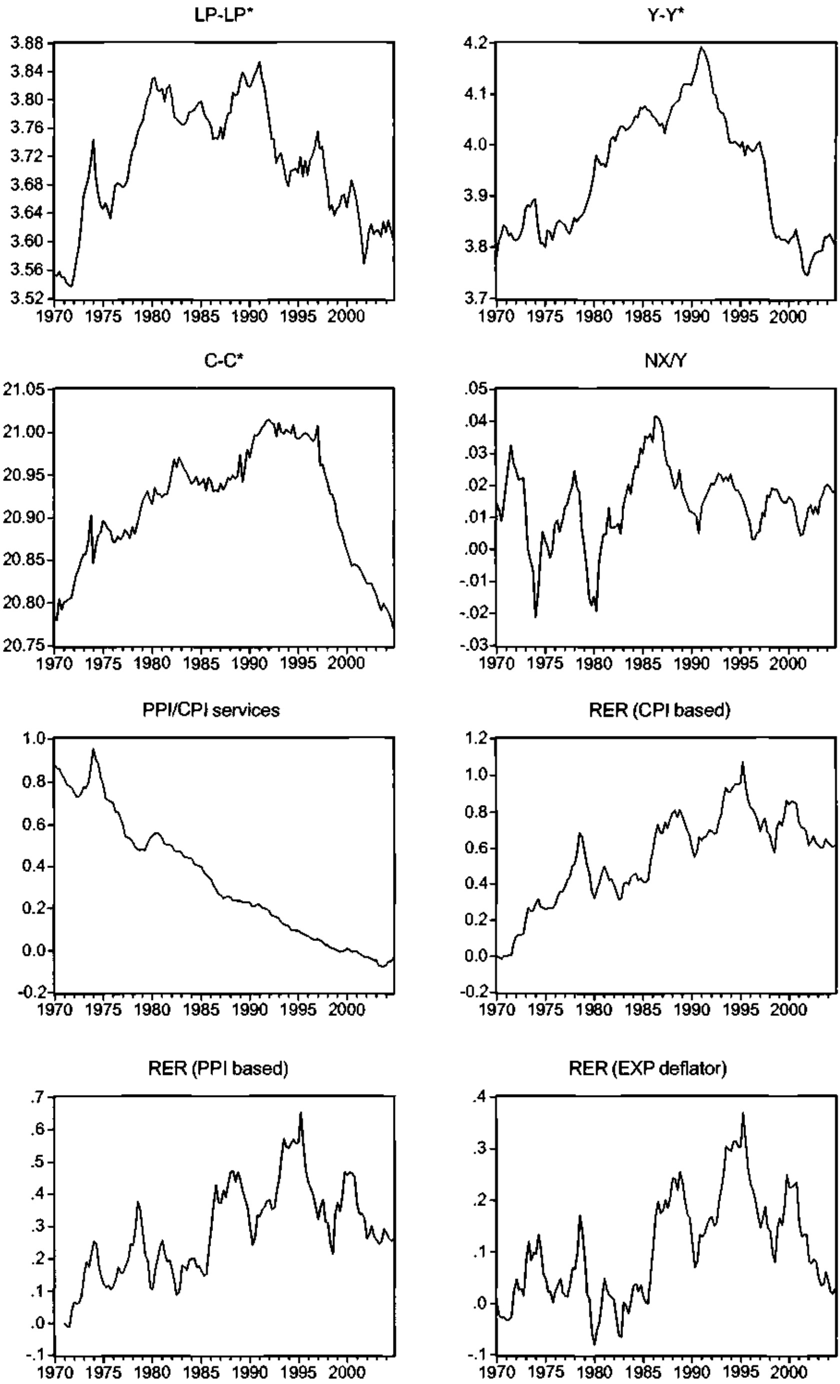

Figure 3A.2
Japan VAR Data

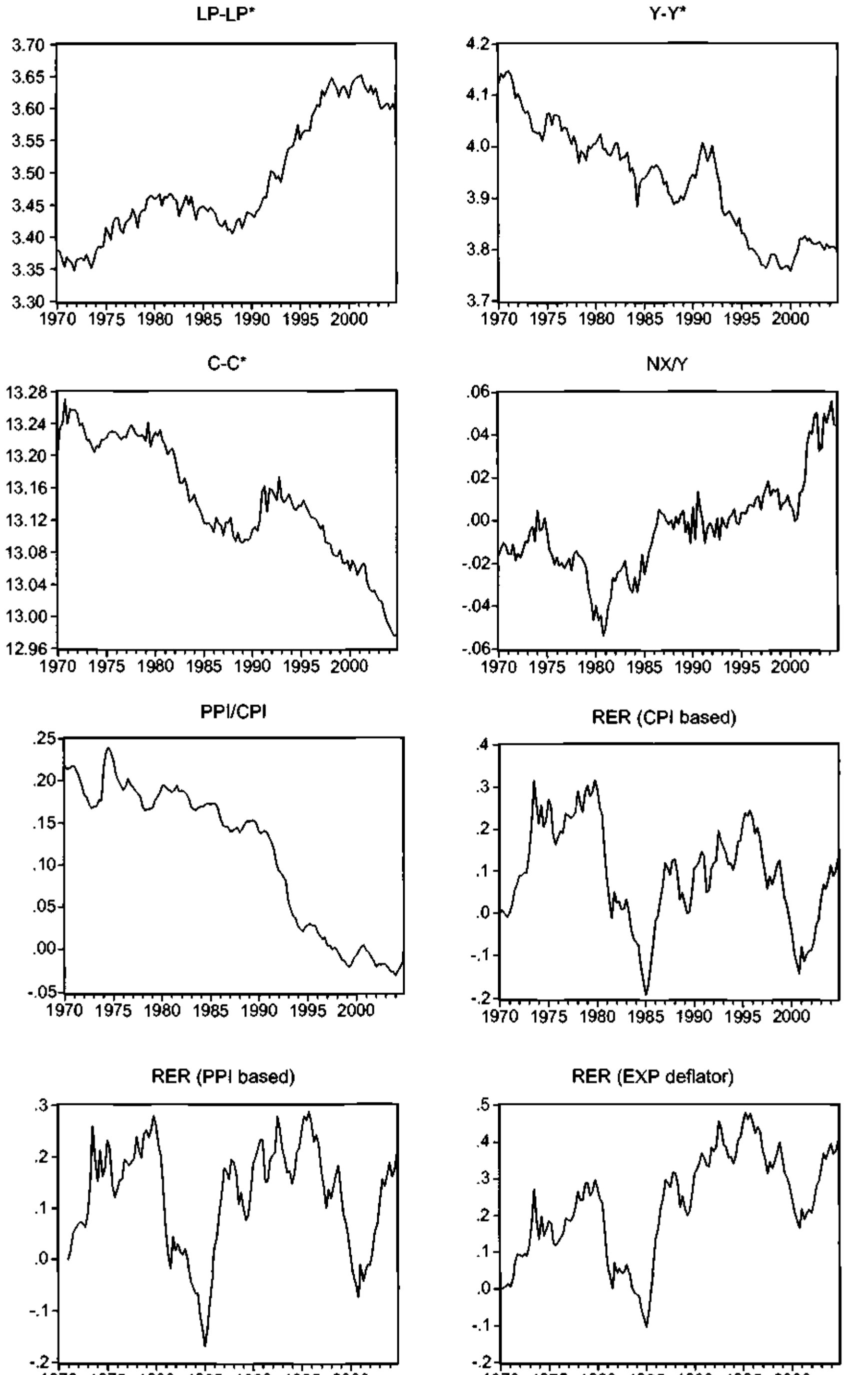

Figure 3A.3
Germany VAR Data

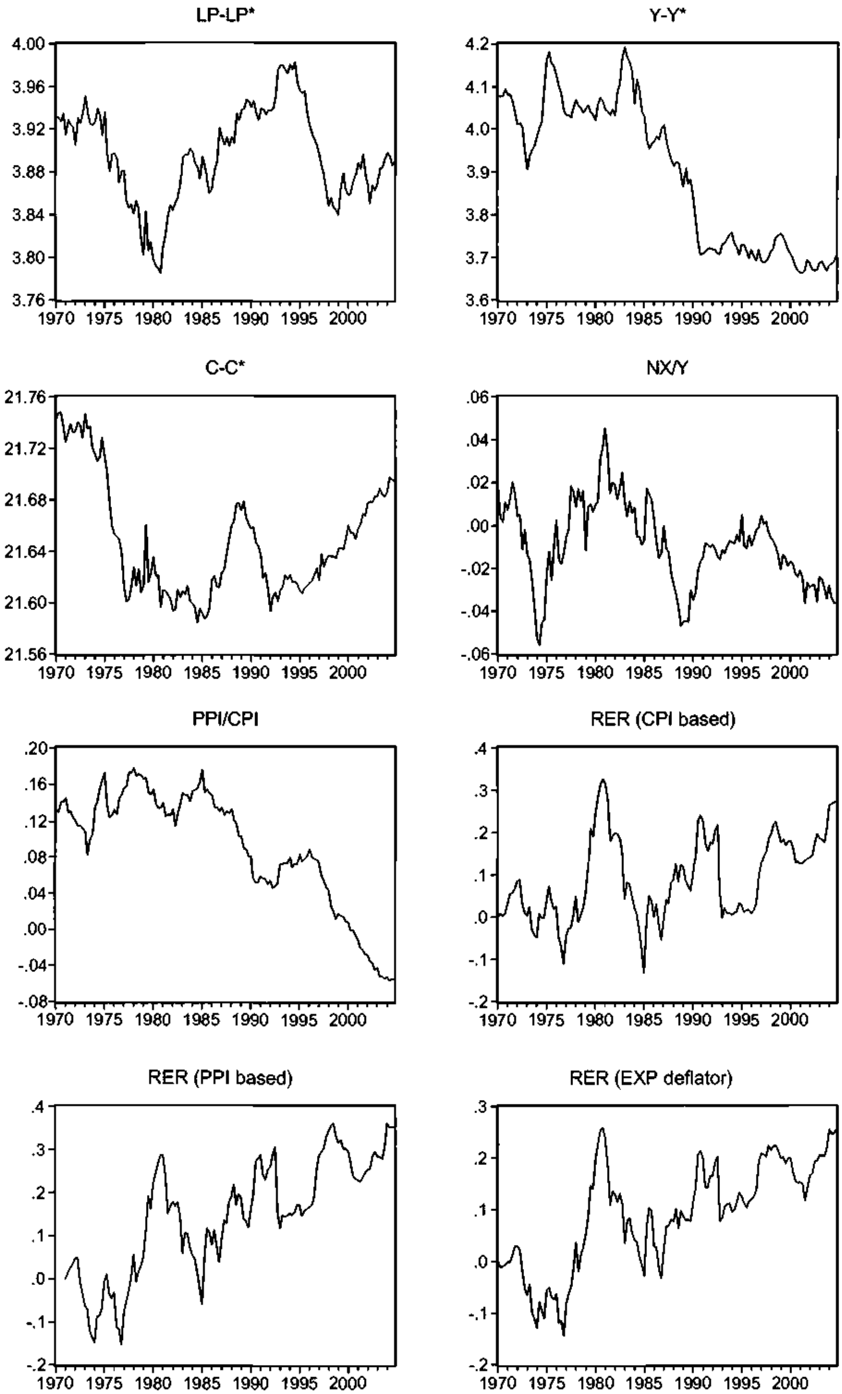

Figure 3A.4
U.K. VAR Data

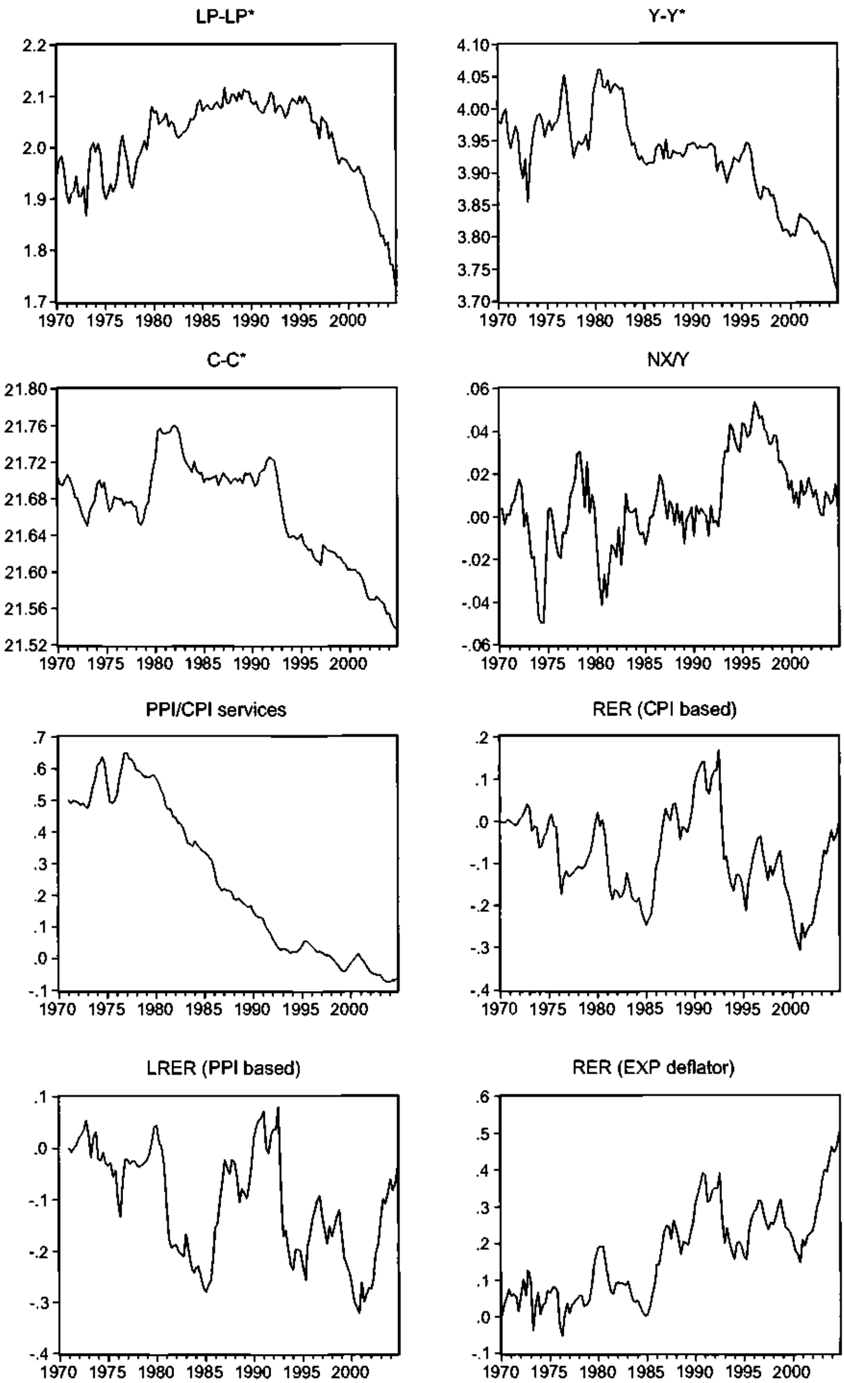

Figure 3A.5
Italy VAR Data

Appendix B Model description

Our world economy consists of two countries of equal size, as before denoted by H and F, each specialized in the production of an intermediate, perfectly tradable good. In addition, each country produces a nontradable good. This good is either consumed or used to make intermediate tradable goods H and F available to domestic consumers. In what follows, we describe our setup focusing on the home country, with the understanding that similar expressions also characterize the foreign economy—whereas starred variables refer to foreign firms and households.

The Firms' Problem

Firms producing home tradables (H) and home nontradables (N) are perfectly competitive and employ a technology that combines domestic labor and capital inputs, according to the following Cobb-Douglas functions:

$$Y_H = Z_H K_H^{1-\xi} L_H^{\xi}$$

$$Y_N = Z_N K_N^{1-\varsigma} L_N^{\varsigma},$$

where Z_H and Z_N are exogenous random disturbances, independent across sectors and countries. Consistent with our empirical methodology, we assume that Z_H follows a unit root process. In turn, Z_N follows an AR(1) process with autocorrelation coefficient equal to 0.95. We assume that capital and labor are freely mobile across sectors. The problem of these firms is standard since they hire labor and capital from households to maximize their profits:

$$\pi_H = \overline{P}_{H,t} Y_{H,t} - W_t L_{H,t} - R_t K_{H,t}$$

$$\pi_N = P_{N,t} Y_{N,t} - W_t L_{N,t} - R_t K_{N,t},$$

where $\overline{P}_{H,t}$ is the wholesale price of the home traded good and $P_{N,t}$ is the price of the nontraded good. W_t denote the wage rate, while R_t represents the capital rental rate.

Firms in the distribution sector are also perfectly competitive. They buy tradable goods, and distribute them to consumers using nontraded goods as the only input in production. We assume that bringing one unit of traded goods to home (or foreign) consumers requires η units of the home (or foreign) nontraded goods.

The Household's Problem

Preferences The representative home agent in the model maximizes the expected value of her lifetime utility, given by:

$$E\left\{\sum_{t=0}^{\infty} U[C_t, \ell_t]\exp\left[\sum_{\tau=0}^{t-1} - v(U[C_\tau, \ell_\tau])\right]\right\} \tag{A1}$$

where instantaneous utility U is a function of a consumption index (C) and leisure, $(1 - \ell)$. Foreign agents preferences are symmetrically defined. It can be shown that, for all parameter values used in the quantitative analysis below, these preferences guarantee the presence of a locally unique symmetric steady-state, independent of initial conditions.

The full consumption basket (C_t) in each country is defined by the following CES aggregator:

$$C_t \equiv [a_T^{1-\phi} C_{T,t}^{\phi} + a_N^{1-\phi} C_{N,t}^{\phi}]^{1/\phi}, \ \phi < 1, \tag{A2}$$

where a_T and a_N are the weights on the consumption of traded and nontraded goods (respectively), and $1/(1 - \phi)$ is the constant elasticity of substitution between $c_{N,t}$ and $C_{T,t}$. The consumption index of traded goods $C_{T,t}$ including both domestically produced goods C_H, and goods produced abroad C_F, is given by:

$$C_{T,t} = [a_H^{1-\rho} C_{H,t}^{\rho} + a_F^{1-\rho} C_{F,t}^{\rho}]^{1/\rho}, \ \rho < 1.$$

Price indexes A notable feature of our specification is that, because of distribution costs, there is a wedge between the producer price and the consumer price of each good. Let $\bar{P}_{H,t}$ and $P_{H,t}$ denote the price of the home traded good at the producer and consumer level, respectively. Let $P_{N,t}$ denote the price of the nontraded good that is necessary to distribute the tradable one. With competitive firms in the distribution sector, the consumer price of the traded good is simply:

$$P_{H,t} = \bar{P}_{H,t} + \eta P_{N,t}. \tag{A3}$$

We hereafter write the utility-based CPIs as:

$$P_t = [a_T P_{T,t}{}^{\phi/(\phi-1)} + a_N P_{N,t}{}^{\phi/(\phi-1)}]^{(\phi-1)/\phi}. \tag{A4}$$

Whereas the price index of tradables is given by:

$$P_{T,t} = [a_H P_{H,t}^{\rho/(\rho-1)} + (1 - a_H) P_{F,t}^{\rho/(\rho-1)}]^{(\rho-1)/\rho}.$$

Foreign prices, denoted with an asterisk and expressed in the same currency as home prices, are similarly defined. We take the price of home aggregate consumption P_t to be the numeraire.

Budget constraints and asset markets We assume that international asset markets are incomplete. home and foreign agents can only hold an international bond (B_H) which pays in units of home aggregate consumption and is zero in net supply. Agents derive income from working ($W_t\ell_t$), from renting capital to firms (R_tK_t), and from interest payments $[(1 + r_t)B_{H,t}]$, where r_t is the real bond's yield, paid at the beginning of period t but known at time $t - 1$. The individual flow budget constraint for the representative agent in the Home country is therefore:

$$P_{H,t}C_{H,t} + P_{F,t}C_{F,t} + P_{N,t}C_{N,t} + B_{H,t+1} + \overline{P}_{H,t}I_{Ht} \leq W_t\ell_t + R_tK_t + (1 + r_t)B_{H,t}. \tag{A5}$$

We assume that the investment is carried out in home tradable goods, and that the capital stock (K) can be freely reallocated between the traded (K_H) and nontraded (K_N) sectors:

$$K = K_H + K_N.$$

As opposed to consumption goods, we assume investment goods do not require distribution services. The price of investment is, therefore, equal to the wholesale price of the domestic traded good ($\overline{P}_{H,t}$). The law of motion for the aggregate capital stock is given by:

$$K_{t+1} = I_{H,t} + (1 - \delta)K_t \tag{A6}$$

The households problem then consists of maximizing lifetime utility, defined by (A1), subject to the constraints (A5) and (A6).

Model calibration

Note that we assume symmetry across countries. We assume a utility function of the form:

$$U[C_t, \ell_t] = \frac{[(\aleph_t C_t)^{\alpha}(1 - \ell_t)^{1-\alpha}]^{1-\sigma} - 1}{1 - \sigma}, \quad 0 < \alpha < 1, \quad \sigma > 0, \tag{A7}$$

where $\aleph_t$ is a taste shock assumed to follow an AR(1) process with autocorrelation coefficient equal to 0.95, and standard deviation set to 0.7

percent. The variable α is set so that in steady-state, one third of the time endowment is spent working; σ (risk aversion) is set equal to two. Following Schmitt-Grohe and Uribe (2003), it is assumed that the endogenous discount factor depends on the taste shock, the average per capita level of consumption (C_t), hours worked (ℓ_t), and has the following form:

$$\nu[U(C_t,\ell_t)] = \begin{cases} \ln(1 + \psi[(C_t)^{\alpha}(1 - \ell_t)^{1-\alpha}]) & \sigma \neq 1 \\ \ln(1 + \psi[\alpha \ln(C_t) + (1 - \alpha)\ln(1 - \ell_t)]) & \sigma = 1 \end{cases},$$

where ψ is chosen such that the steady-state real interest rate is 1 percent per quarter. This parameter also determines the speed of convergence to the unique nonstochastic steady-state.

Because of the presence of a distribution sector in our model, the trade elasticity is given by $\omega(1 - \mu)$. Following the calibration in Burstein, Neves, and Rebelo (2003), we set distribution costs to 50 percent. We then set the elasticity of substitution ω to either two or eight, implying a trade elasticity of one and four (respectively).

The value of ϕ is selected based on the available estimates for the elasticity of substitution between traded and nontraded goods. We use the estimate by Mendoza [1991], and referred to a sample of industrialized countries and set that elasticity equal to 0.74. Stockman and Tesar (1995) estimate a lower elasticity (0.44), but their sample includes both developed and developing countries.

The weights of domestic and foreign tradables in the tradables consumption basket (C_T), a_H and a_F (normalized to $a_H + a_F = 1$) are chosen such that imports are 5 percent of aggregate output in steady state. This corresponds to the average ratio of U.S. imports from Europe, Canada, and Japan to U.S. GDP between 1960 and 2002. The weights of traded and nontraded goods (a_T and a_N) are chosen as to match the share of nontradables in the U.S. consumption basket. Over the period 1967–2002, this share is equal to 53 percent on average. Consistently, Stockman and Tesar (1995) suggest that the share of nontradables in the consumption basket of the seven largest OECD countries is roughly 50 percent. Finally, we calibrate ξ and ζ, the labor shares in the production of tradables and nontradables, based on the work of Stockman and Tesar (1995). We set the depreciation rate of capital equal to 2.5 percent quarterly.

Comment

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The chapter by Corsetti, Dedola, and Leduc is stimulating and thought provoking. It makes the interesting claim that international variables—the real exchange rate and the trade balance—do not move as expected after a technology shock. As the authors note, this claim (if confirmed) would have strong implications for medium-run forecasts of international adjustments in the current world economy. The United States is currently running a large trade deficit, and is experiencing productivity growth rates far in excess of other major industrialized countries. One might reasonably expect that high productivity would be the cure to large trade deficits: higher U.S. productivity would lower the prices of its exports, depreciate the real exchange rate, and (once J-curve effects had passed) shrink the trade gap. On the other hand, if the authors claims are correct, then one should not expect this self correcting mechanism to work smoothly, or at all.

It is useful to note that the trade balance, and the real exchange rate results are not equally surprising. For example, in the well-known paper of Backus, Kehoe, and Kydland (1994), a favorable productivity shock in the home country leads to a persistent trade deficit. Capital accumulation is the key to this result: higher home productivity leads to a capital inflow, in order to take advantage of high returns. On the other hand, in the BKK paper and in the vast majority of its successors, a favorable productivity shock leads (unambiguously) to a real exchange rate depreciation. This is not to say that one cannot write down a microfounded dynamic general equilibrium (DGE) model in which a favorable productivity shock leads to a real exchange rate appreciation since the work of these authors (in an earlier paper) shows that one can.[1] But one has to work hard, and the assumptions needed are strong.

Given the presumption from most previous theoretical work in this area that the real exchange rate should depreciate following an improvement in productivity, it seems reasonable to bring additional evidence to bear on this key question. Here results from Basu, Fernald, and Kimball (2006) are reproduced. BFK identify technology shocks as innovations to a purified Solow residual that has been cleansed of mismeasurement coming from variable input utilization, scale economies, and aggregation biases. Figure 3C1.1 shows the impulse responses of output, consumption of nondurables and services, net exports relative to GDP, and the real exchange rate to a 1 percentage point innovation in the purified Solow residual.[2] The real exchange rate (RER) is the broad, trade-weighted measure produced by the Federal Reserve Board. All estimates use annual data. The sample for the RER is 1973–1996, while for the other responses the sample is 1952–96.[3]

Over several years, technology shocks raise output and consumption to permanently higher levels. Net exports show no statistically significant response, although the sign is generally positive. The RER shows a large and significant depreciation in response to a favorable technology

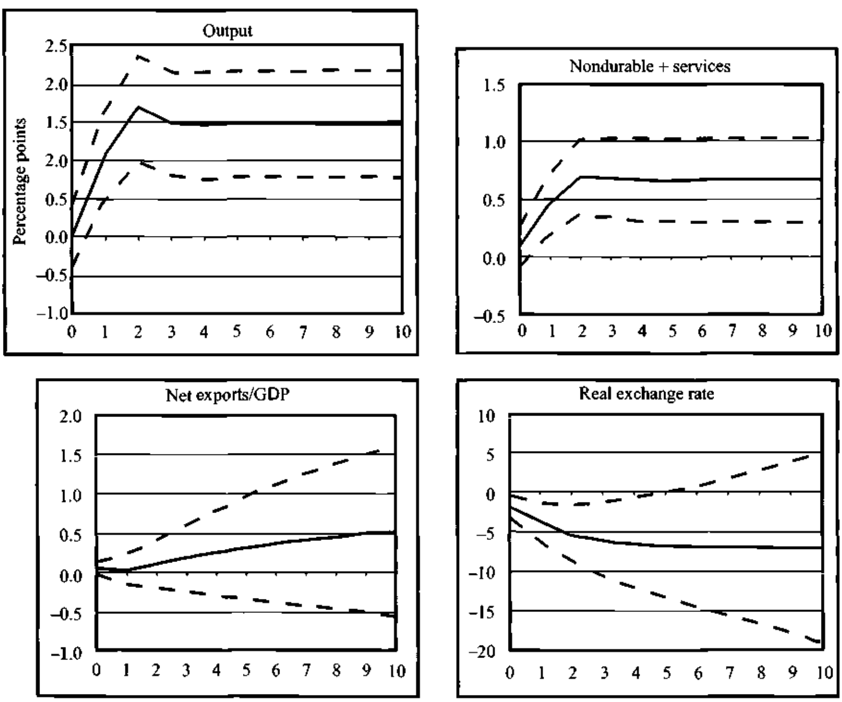

Figure 3C1.1
Impulse responses from Basu, Fernald, and Kimball (2006)

innovation.[4] Of course, this result is the opposite of that found in the chapter.

Since the RER result is the key feature of this paper, and is also the central motivation for the modeling exercise in the authors' earlier paper, it seems worthwhile to try and figure out why they obtain results different from those of BFK.

First, BFK study economy-wide shocks, while the chapter's shocks are for manufacturing only. It is not clear why this difference should matter so much for the RER results, but the authors can and should check to see if it matters. Since the BFK measure of aggregate technology is built from industry measures, the authors can construct a manufacturing-only version of the BFK measure, and repeat the exercise for the RER. In fact, they can do better. Since not all manufactured goods are traded, they can assemble a better measure of manufacturing tradables from the industry data than the total manufacturing measure they have now.

Second, BFK use a Solow residual to identify technology shocks, while the chapter follows the long-run identification method of Galì (1999). BFK report that the annual shocks identified using these different schemes have a correlation of about 0.75, but it is certainly possible that the difference between the two shocks might matter for the RER results. Again, this possibility can and should be checked—although if this is the source of the difference, it is unclear which measure/result should be preferred.

Third possibility: BFK (as well as Galì 1999) identify absolute shocks to the technology level in a given country, usually the United States. The chapter identifies relative shocks, with the exception of the robustness check in figure 3.12 of their paper, which is discussed below.

This last difference seems quite important. Both Galì and BFK see themselves as identifying exogenous shocks to technology. (Recent literature establishes that although the Galì shock could (in principle) include changes in capital tax rates, this does not appear to be the case in the data.) But for the group of countries examined in the chapter, technology should be common, especially in the long run. In the short run, countries might be affected differently by the same technology shock because they specialize in producing different goods. But again, it is difficult to discern exogenous sources of long-run variation in the composition of manufacturing output across these wealthy, industrialized countries (Imbs 2003). Thus, chances are good that the shock being identified in the chapter exercise is substantially non technological in nature.

What might these shocks be? Their nature is likely to vary across countries. But suppose a country imposes stricter labor market regulations than the others in its ROW—this is a plausible source of permanent, cross-country differences. Suppose also that the regulations raise the effective cost of labor, so that from a firms point of view they are equivalent to labor taxes. Then a cost minimizing firm will respond by substituting capital for labor, thus raising labor productivity. But since this shock is an increase in the total cost of producing output, the RER will rise.

Let me make my point by using the chapter's results for Germany (level specification), which I freely admit I have picked in order to make the most favorable case. The identified shock raises labor productivity, but also lowers relative German output, which is hard to reconcile with a favorable technology shock. However, the fall in output, the rise in the RER, and the decline in NX/Y are all consistent with my interpretation.

The rise in relative consumption is not. One could (of course) spin a story that stricter labor market regulations either have the direct effect of providing higher income to poor rule-of-thumb/buffer-stock consumers who have a high marginal propensity to consume (MPC), or such regulations are positively correlated with policies that have this effect. Without such elaboration, this evidence is at odds with the hypothesis. But I hesitate to over interpret a positive impulse response that is marginally significant at the 68 percent level. Parenthetically, all of the confidence intervals plotted in the paper are the 16th and 84th percentiles of the posterior distributions, and the authors should aim for stricter levels of significance.

The authors are sensitive to the possibility of identifying nontechnology shocks using their procedure, and thus include the producer price index (PPI) for manufacturing relative to the consumer price index (CPI) for services as a check. If their shock lowers this relative price, then they believe they have identified a technology shock.

Alas, one cannot be sanguine about this favorable interpretation. The reason is that at the level of national accounts data we never observe output and prices independently: the manufacturing output data in the labor productivity variable are just nominal output deflated essentially by the PPI for manufacturing. Any white noise measurement errors made by national income accountants when estimating PPI inflation will translate into permanent errors in the levels of output (and hence labor productivity) and prices, with opposite signs. Thus, regressing price innovations on permanent output/labor productivity innovations is (practically) guaranteed to produce a negative sign since much of the variation in the two series is likely to be driven by the same measurement error.[5]

To be fair, the labor market regulation hypothesis seems less plausible in Japan and the United States. In those two countries, both consumption and output show positive responses to the identified long-run shock to labor productivity, albeit with the same caveats regarding statistical significance. But this points to the need for deeper investigation into the interpretation of these shocks at the level of individual countries.

In response to my comments on an earlier draft, in this version of their paper the authors examine impulse responses of their usual variables in response to an absolute technology shock, identified as in Galì (1999). As they point out, the impulse responses to the long-run absolute shocks (to U.S. labor productivity) in figure 3.12 are very close to those estimated for the long-run relative shocks in figure 3C.1

It is not clear that this finding should be reassuring. On a priori grounds, one would expect most technology shocks in a rich country like the United States to diffuse to other rich countries in relatively short order. This is why it is unclear that a long-run relative shock would even be technological in nature, as discussed above. But the impulse responses to the absolute and relative shocks are nearly indistinguishable in forty quarters—ten years—after the shocks occur. This suggests that the shocks being identified in one or both exercises are unlikely to be technological in nature.

The authors can address this issue using their Monte Carlo exercise in the penultimate section of the paper. They now simulate data and estimate impulse responses to relative technology shocks. They can repeat their exercise for absolute shocks under different assumptions about the speed of diffusion of these shocks to the ROW. However, the model may need to be modified to carry out this exercise. Appendix B currently suggests that technology diffusion is not guaranteed (shocks are independently and identically distributed [i.i.d.] across countries), which means that with random-walk shocks in the manufacturing sectors of the two countries their per capita incomes could drift arbitrarily far apart. If correct, this is an undesirable feature of the model, which can also cause technical problems, since the linear probability (VAR) models (that are estimated on the simulated data) are unlikely to be good approximations to the true data generating process.

Some suggestions: First, ascertain the correlation between the relative labor productivity shocks in this paper, and the standard absolute shocks identified as in Galì or BFK. If the correlation is high, then there may be more confidence that these shocks are technological in nature. Second, compute and report the variance of output level fluctuations (not relative output fluctuations) accounted for by the relative shocks. Technological shocks should matter relatively less at short horizons and be dominant sources of variability in the long run. Do these shocks display that pattern?

Finally, the authors should try repeating their exercise with the BFK shocks. There is an unresolved debate in the literature about the usefulness of long-run identifying restrictions (Christiano, Eichenbaum, and Vigfusson 2006), so this robustness check would be valuable. For example, by definition long-run restrictions cannot identify persistent but ultimately transitory technology shocks. If these shocks are important in the data, then the average impulse response may look quite different than the response to permanent shocks alone, which is all that the authors can identify now, even in the best case scenario. The BFK procedure, unlike the long-run method, will identify both permanent and transitory technology shocks.

The research agenda of which this paper is a part has introduced a novel and potentially important hypothesis and developed interesting models. However, strong claims require strong evidence, and the evidence for non standard RER responses to technology shocks is not yet compelling.

Notes

1. Corsetti, Dedola, and Leduc (2004).

2. The Solow residual is estimated to be very close to a random walk, and so its own impulse response, which would be a horizontal line, is not shown.

3. Dashed lines show 95 percent confidence intervals, computed using the RATS Monte Carlo procedure.

4. Note that a 1 percentage point innovation in technology is estimated to depreciate the RER by about 5 percentage points. BFK add the following caveat regarding the RER results: "a word of caution: the sharp appreciation of 1980–85 and depreciation of 1985–88 dominate the data. Adding separate dummies for those two periods reduces both the magnitude and statistical significance of the estimate, which does remain negative" (Basu, Fernald, and Kimball 2006, 1436).

5. This problem is well known to labor economists in the context of estimating labor supply elasticities by regressing hours worked on wages, if the wage data consist of total earnings divided by hours.

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Comment

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Introduction

What are the effects of technology shocks on the exchange rate, the trade balance, and on domestic and foreign real activity? The Corsetti, Dedola, and Leduc (CDL) chapter is the first paper (to my knowledge) that addresses this empirical question using Vector Autoregression (VAR) techniques. The paper thus fills an important gap in the literature.[1]

CDL use quarterly post-Bretton Woods data for the United States, Japan, Germany, United Kingdom, and Italy. They focus on shocks that improve the technology of a country's manufacturing sector, relative to the technology of foreign (rest of the world, ROW) manufacturing. CDL find that a country-specific positive manufacturing technology shock raises domestic manufacturing output and labor productivity, as well as private consumption (relative to ROW variables), but that it lowers net exports. CDL's baseline VAR model suggests that, in the United Kingdom and Italy, a positive technology shock triggers a real exchange rate (RER) *depreciation;* in the United States and Japan, by contrast, a positive technology shock triggers a RER *appreciation*. CDL consider three measures of the RER, namely measures based on consumer price indices (CPIs), on manufacturing producer price indices (PPIs), and on export prices. For a given country, the reported responses of the three RER measures are qualitatively similar.

The estimated responses of output, consumption, and net exports are consistent with standard economic theory. For example, the increase in (relative) consumption can be rationalized by models with limited international risk sharing and/or consumption home bias (Kollmann 1996, 2001).

Intuitively, an exogenous increase in a country's supply of manufactured goods is expected to lower the relative price of those goods.

Hence, CDL's finding that (in the United States and Japan) a positive manufacturing technology shock triggers a *rise* of the relative price of domestic manufactured goods compared to foreign manufactured goods (appreciation of the RER measures based on manufacturing PPIs and on export prices) challenges conventional wisdom. By contrast, standard theory is consistent with the idea that a positive tradable good (manufacturing) supply shock may appreciate the CPI based RER, due to an increase in the relative price of domestic non-tradables (Balassa-Samuelson effect).

Robustness of Results

In what follows, the robustness of CDL's results will be investigated. I use the same econometric method as CDL, but consider *annual* data for a larger set of thirteen OECD countries (see table 3C2.1).[2] The sample period is 1973–2003. A VAR in first differenced variables is separately fitted to each country (see CDL's equation (2)).[3] In the baseline specification used here, the vector of first differenced variables used for the country *j* VAR is:

$$Z^k_{j,t} \equiv [\Delta \ln x_{j,t}, \Delta \ln Y_{j,t}, \Delta \ln C_{j,t}, \Delta NX_{j,t}, \Delta \ln RER^k_{j,t}],$$

where $x_{j,t}$, $Y_{j,t}$, and $C_{j,t}$, are manufacturing output per hour worked, manufacturing output, and private consumption in country *j*, (respectively) expressed as ratios of corresponding ROW aggregates; $NX_{j,t}$ is *j*'s net export divided by *j*'s GDP; $RER^k_{j,t}$ (with $k = C, X$) is *j*'s real exchange rate (vis-à-vis ROW); and a rise in $RER^k_{j,t}$ represents an appreciation. I consider two real exchange rate measures: a CPI based measure ($RER^C_{j,t}$), and a measure based on export prices ($RER^X_{j,t}$).[4] Note that the baseline specification here includes the same variables as CDL's VAR—with the following exceptions: no PPI/CPI ratios and no PPI-based RER measures are used here, due to gaps in the PPI series (for several countries). The results below are based on VARs of order one.[5] The data are described in the Appendix.

For each country, the tables below report median responses to a positive one standard deviation country-specific innovation to manufacturing technology. The median responses are based on one thousand draws from the posterior distribution of the VAR parameters, obtained using CDL's Bayesian approach. For each variable, the posterior probability is also shown that the response of that variable is positive (see figures in parentheses).

Table 3C2.1
Baseline VAR Model: Dynamic Responses to Exogenous Technology Shock (in %)

	Country												
	US	CA	AU	JP	BE	DK	FR	DE	IT	NL	NO	SE	UK
Impact responses													
x	**1.12**	**1.53**	**1.24**	**2.30**	**1.86**	**2.78**	**1.43**	**0.82**	**2.70**	**1.58**	**1.69**	**2.45**	**1.35**
	(.97)	*(.99)*	*(.99)*	*(.99)*	*(.99)*	*(.99)*	*(.99)*	*(.95)*	*(.95)*	*(.99)*	*(.99)*	*(.99)*	*(.99)*
Y	−0.76	−0.05	−0.13	**2.45**	**0.63**	**1.21**	**1.04**	0.26	**1.64**	0.01	0.48	**1.99**	−0.40
	(.20)	*(.44)*	*(.48)*	*(.94)*	*(.98)*	*(.85)*	*(.99)*	*(.72)*	*(.94)*	*(.56)*	*(.63)*	*(.97)*	*(.26)*
C	0.21	0.01	0.20	**1.01**	**−0.66**	0.31	**0.52**	0.00	**0.86**	−0.63	−0.61	−0.15	0.23
	(.65)	*(.55)*	*(.66)*	*(.93)*	*(.10)*	*(.62)*	*(.89)*	*(.52)*	*(.87)*	*(.17)*	*(.19)*	*(.41)*	*(.62)*
NX	0.05	0.23	**0.44**	−0.13	0.25	0.05	−0.19	**0.49**	−0.26	**0.59**	−0.87	**0.35**	−0.14
	(.68)	*(.72)*	*(.90)*	*(.25)*	*(.82)*	*(.58)*	*(.19)*	*(.90)*	*(.24)*	*(.86)*	*(.21)*	*(.89)*	*(.31)*
RER^C	0.62	**2.09**	**5.00**	−1.37	**−1.58**	**−1.49**	**−1.52**	1.37	**−3.41**	0.30	0.31	−1.70	**3.07**
	(.59)	*(.93)*	*(.97)*	*(.34)*	*(.13)*	*(.09)*	*(.09)*	*(.83)*	*(.08)*	*(.60)*	*(.59)*	*(.19)*	*(.93)*
RER^X	0.68	1.03	**1.60**	−0.03	**−0.89**	**−1.20**	**−1.81**	−0.56	**−2.44**	−0.47	**−3.72**	−0.99	−0.20
	(.66)	*(.81)*	*(.89)*	*(.49)*	*(.08)*	*(.09)*	*(.07)*	*(.28)*	*(.04)*	*(.25)*	*(.09)*	*(.22)*	*(.44)*
Responses 2 years after shock													
x	**2.96**	**2.94**	**1.82**	**2.79**	**3.46**	**2.97**	**2.05**	**1.19**	**3.98**	**2.72**	**2.26**	**4.52**	**3.85**
	(.99)	*(.99)*	*(.99)*	*(.99)*	*(.99)*	*(.99)*	*(.99)*	*(.99)*	*(.94)*	*(.99)*	*(.99)*	*(.99)*	*(.99)*
Y	0.26	−0.06	−0.32	**3.72**	**1.56**	0.97	**1.67**	0.37	**3.69**	0.39	0.32	**5.99**	0.73
	(.56)	*(.45)*	*(.44)*	*(.95)*	*(.98)*	*(.73)*	*(.99)*	*(.65)*	*(.94)*	*(.82)*	*(.51)*	*(.99)*	*(.68)*
C	**1.61**	−0.44	**1.18**	**2.19**	−0.60	0.37	0.40	1.08	**1.88**	0.21	−1.06	0.71	0.49
	(.96)	*(.36)*	*(.89)*	*(.96)*	*(.23)*	*(.61)*	*(.70)*	*(.73)*	*(.89)*	*(.57)*	*(.19)*	*(.72)*	*(.66)*
NX	−0.19	0.36	0.25	−0.30	0.33	−0.12	−0.07	0.54	−0.07	**1.01**	−0.35	**0.57**	−0.49
	(.24)	*(.72)*	*(.69)*	*(.19)*	*(.74)*	*(.42)*	*(.43)*	*(.81)*	*(.45)*	*(.88)*	*(.46)*	*(.89)*	*(.18)*

RER^C	1.32	−1.44	2.56	−1.33	**−2.33**	−0.75	**−3.13**	**3.20**	−2.65	−0.20	0.92	0.56	−1.34
	(.62)	(.22)	(.79)	(.39)	(.14)	(.27)	(.02)	(.95)	(.22)	(.46)	(.71)	(.62)	(.35)
RER^X	0.93	−0.67	0.50	−1.08	**−2.00**	**−1.56**	**−2.50**	0.55	**−2.59**	0.38	−2.79	−0.37	−1.45
	(.62)	(.36)	(.60)	(.32)	(.02)	(.07)	(.06)	(.65)	(.07)	(.66)	(.26)	(.42)	(.26)
Responses 10 years after shock													
x	**3.72**	**2.64**	**1.88**	**2.98**	4.09	3.17	**2.10**	**1.45**	**4.68**	**2.79**	**2.30**	**3.89**	**4.44**
	(.99)	(.99)	(.99)	(.99)	(.99)	(.99)	(.99)	(.99)	(.95)	(.99)	(.99)	(.99)	(.99)
Y	0.90	0.14	−0.31	**4.03**	**1.73**	0.91	**1.58**	0.27	**5.40**	0.37	0.24	**5.63**	**2.09**
	(.73)	(.54)	(.42)	(.94)	(.98)	(.69)	(.98)	(.58)	(.94)	(.80)	(.51)	(.99)	(.93)
C	**2.44**	−0.41	**1.12**	**2.37**	−0.56	0.37	0.32	1.22	**3.04**	0.24	−1.10	1.02	1.02
	(.97)	(.39)	(.86)	(.95)	(.28)	(.58)	(.65)	(.75)	(.90)	(.58)	(.19)	(.80)	(.77)
NX	−0.38	0.38	0.26	−0.33	0.35	−0.15	−0.08	0.55	−0.12	**1.04**	−0.32	**0.47**	**−0.87**
	(.13)	(.74)	(.70)	(.22)	(.70)	(.40)	(.43)	(.79)	(.43)	(.89)	(.49)	(.84)	(.09)
RER^C	0.20	−1.33	1.84	−1.40	**−2.62**	−0.59	**−3.12**	**3.56**	−2.68	−0.24	0.95	0.94	−2.05
	(.51)	(.25)	(.75)	(.41)	(.15)	(.35)	(.02)	(.95)	(.26)	(.44)	(.71)	(.68)	(.26)
RER^X	−0.01	−0.97	0.13	−0.98	**−2.34**	**−1.58**	**−2.45**	0.40	**−2.24**	0.30	−2.62	0.54	−2.14
	(.49)	(.32)	(.54)	(.34)	(.02)	(.06)	(.06)	(.61)	(.13)	(.63)	(.31)	(.72)	(.20)

Notes: The columns labeled US, CA, etc. show responses of different countries to a one standard deviation country-specific innovation to manufacturing technology. CA: Canada; AU: Australia; JP: Japan; BE: Belgium; DK: Denmark; FR: France; DE: Germany; IT: Italy; NL: Netherlands; NO: Norway; SE: Sweden.

The rows labeled x, Y, etc. show responses of the corresponding variables. x: a country's manufacturing labor productivity (relative to manufacturing productivity in the rest of the world, ROW); Y: manufacturing output (relative to ROW manufacturing output); C: consumption (relative to ROW consumption); NX: net exports (normalized by GDP); RER^C: CPI based real exchange rate; RER^X: real exchange rate based on export prices. Responses of x, Y, C, RER^C, and RER^X are expressed as percentage deviations from an unshocked path. Responses of NX are expressed as differences from the unshocked path.

The table reports median responses based on the posterior distribution of VAR parameters. Figures in parentheses: posterior probability that response is positive. **Bold font**: responses for which the interval between the 16th and 84th percentiles of the posterior distribution does not include zero.

Table 3C2.2
Alternative VAR Models: Responses to Exogenous Technology Shock (in %)

	Country												
	US	CA	AU	JP	BE	DK	FR	DE	IT	NL	NO	SE	UK
	(a) Bivariate VAR: labor productivity and real exchange rate												
Impact responses													
RER^C	–0.73	0.13	–0.51	**–3.48**	**–2.13**	**–1.58**	**–2.19**	–0.85	**–2.51**	0.36	–0.02	**–2.76**	–0.14
	(.39)	*(.51)*	*(.42)*	*(.10)*	*(.03)*	*(.03)*	*(.01)*	*(.28)*	*(.07)*	*(.60)*	*(.49)*	*(.05)*	*(.47)*
RER^X	–0.13	0.67	0.37	–0.98	**–1.07**	**–1.79**	**–2.03**	**–1.41**	**–2.25**	0.26	–0.53	**–2.07**	–1.25
	(.47)	*(.73)*	*(.60)*	*(.25)*	*(.02)*	*(.00)*	*(.03)*	*(.14)*	*(.01)*	*(.61)*	*(.42)*	*(.05)*	*(.19)*
Responses 2 years after shock													
RER^C	–0.07	**–4.30**	–0.90	**–3.90**	**–2.64**	–0.79	**–3.25**	0.66	–0.83	–0.06	0.36	–0.47	**–3.68**
	(.48)	*(.01)*	*(.38)*	*(.13)*	*(.05)*	*(.19)*	*(.00)*	*(.68)*	*(.35)*	*(.48)*	*(.63)*	*(.40)*	*(.06)*
RER^X	–0.72	–1.39	–0.19	**–2.39**	**–2.11**	**–1.82**	**–2.35**	–0.42	**–2.11**	0.68	–0.02	–1.37	**–2.54**
	(.39)	*(.17)*	*(.46)*	*(.11)*	*(.01)*	*(.02)*	*(.02)*	*(.39)*	*(.04)*	*(.77)*	*(.49)*	*(.23)*	*(.08)*
Responses 10 years after shock													
RER^C	0.17	**–3.90**	–0.87	**–3.86**	**–2.68**	–0.56	**–3.52**	0.81	–0.68	–0.10	0.51	–0.46	**–5.45**
	(.52)	*(.02)*	*(.37)*	*(.13)*	*(.07)*	*(.24)*	*(.00)*	*(.70)*	*(.38)*	*(.47)*	*(.66)*	*(.42)*	*(.04)*
RER^X	–0.84	**–1.66**	–0.19	**–2.39**	**–2.50**	**–1.82**	**–2.42**	–0.41	**–2.14**	0.67	–0.03	–1.12	**–3.36**
	(.39)	*(.14)*	*(.46)*	*(.11)*	*(.01)*	*(.02)*	*(.02)*	*(.39)*	*(.03)*	*(.77)*	*(.49)*	*(.27)*	*(.08)*

	(b) Five variable VAR: labor productivity, output, CPI, government purchases, RER												
Impact responses													
RER^C	–0.83	**2.21**	1.27	–2.44	0.15	–0.35	**–1.58**	–0.24	**–2.29**	0.58	–0.83	–1.17	**2.63**
	(.34)	*(.96)*	*(.68)*	*(.23)*	*(.57)*	*(.36)*	*(.11)*	*(.46)*	*(.12)*	*(.70)*	*(.28)*	*(.24)*	*(.89)*
RER^X	0.25	1.13	–0.06	0.01	–0.10	–0.44	**–1.57**	–0.01	**–1.71**	–0.58	–1.98	–0.38	–0.91
	(.59)	*(.82)*	*(.48)*	*(.51)*	*(.40)*	*(.30)*	*(.11)*	*(.49)*	*(.15)*	*(.31)*	*(.28)*	*(.35)*	*(.26)*
Responses 2 years after shock													
RER^C	–2.69	–1.42	–1.64	–2.32	–1.03	–0.28	**–2.68**	1.39	–2.01	0.06	0.56	0.57	–1.30
	(.26)	*(.26)*	*(.31)*	*(.31)*	*(.26)*	*(.41)*	*(.08)*	*(.75)*	*(.23)*	*(.53)*	*(.62)*	*(.60)*	*(.31)*
RER^X	–1.79	–0.58	–1.86	–1.62	**–1.39**	**–1.14**	**–2.14**	0.94	–1.64	0.16	–3.61	–0.62	**–1.77**
	(.20)	*(.37)*	*(.25)*	*(.29)*	*(.03)*	*(.14)*	*(.11)*	*(.67)*	*(.19)*	*(.56)*	*(.24)*	*(.39)*	*(.23)*
Responses 10 years after shock													
RER^C	–2.91	–1.58	–2.73	–1.51	–1.61	–0.38	**–3.30**	**2.24**	–0.23	–1.19	0.98	0.88	–2.61
	(.33)	*(.25)*	*(.23)*	*(.38)*	*(.17)*	*(.39)*	*(.09)*	*(.86)*	*(.48)*	*(.28)*	*(.68)*	*(.66)*	*(.17)*
RER^X	–2.32	–0.85	**–2.67**	–1.98	**–1.79**	**–1.29**	**–2.61**	0.98	–3.03	0.00	**–2.91**	0.49	–2.49
	(.20)	(.33)	(.20)	(.26)	(.01)	(.11)	(.13)	(.66)	(.18)	(.51)	(.31)	(.60)	(.19)

Notes: The table reports median responses based on the posterior distribution of VAR parameters. Figures in parentheses: posterior probability that response is positive. **Bold font:** responses for which the interval between the 16th and 84th percentiles of the posterior distribution does not include zero. See table 2 for additional explanations.

Table 3C2.1 reports results for the baseline VAR. Due to space constraints, only impact responses, as well as responses two and ten years after the shock, are reported. In all thirteen countries, a positive country-specific manufacturing technology shock triggers a positive (median) response of manufacturing labor productivity (relative to ROW productivity). On impact, the (median) response of manufacturing output is positive in nine of the thirteen countries; ten years after the shock, twelve countries exhibit a (median) rise in relative output. Relative consumption exhibits a positive (median) response in ten countries, although consumption increases are mostly less significant than output increases. The output and consumption responses in table 3C2.1 are, thus, qualitatively consistent with those reported by CDL.

For three of the five countries considered by CDL, table 3C2.1 reports a (median) fall of net exports, in response to a positive technology shock which is likewise consistent with CDL. However, for the *other* countries in the present sample of thirteen countries, net exports tend to *rise*. Overall, the (median) response of net exports is negative in only about half of the thirteen countries.

On impact, a positive manufacturing technology shocks triggers a (median) *depreciation* of the CPI based RER (RER^C), in six of the thirteen countries; two and ten years after the shock, a (median) RER^C *depreciation* is reported for eight countries. On impact, the export-prices-based RER (RER^X) shows a (median) *depreciation* in ten countries; two and ten years after the shock, a (median) RER^X *depreciation* occurs in nine countries. It has to be noted that the variance of the posterior distribution of the RER^C and RER^X responses is often high.

Table 3C2.2 reports results for alternative VAR models. Panel (a) considers bivariate VARs in first differences of (relative) productivity and of the RER: $Z^k_{j,t} \equiv [\Delta \ln x_{j,t}, \Delta \ln RER^k_{j,t}]$. The bivariate VARs suggest that a positive technology shock generates (median) RER^C and RER^X *depreciations*, in ten or more of the thirteen countries (on impact), as well as two and ten years after the shock. In all countries, labor productivity responds positively to the shock (not shown in table 3C2.2).

CDL study a VAR model that only comprises real variables. Panel (b) of table 3C2.2 considers a five-variable VAR that includes a country's CPI inflation differential vis-à-vis the ROW ($\Delta \ln CPI_{j,t}$), i.e. an indicator of the country's (relative) monetary policy stance. The VAR also includes a fiscal policy measure: the log growth rate of relative (real) government purchases ($G_{j,t}$), specifically the vector of variables used for country j is $Z^k_{j,t} \equiv [\Delta \ln x_{j,t}, \Delta \ln Y_{j,t}, \Delta \ln CPI_{j,t}, \Delta \ln G_{j,t}, \Delta \ln RER^k_{j,t}]$. It appears that a positive country-specific manufacturing technology shock raises (relative) government purchases, and that it lowers the (relative) CPI in eight of the countries (not shown in the table). Panel (b) shows that, on impact, the shock induces a (median) RER^C *depreciation* in eight countries, and a (median) RER^X *depreciation* in ten countries; ten years after the shock, RER^C and RER^X both show (median) *depreciations* in ten countries.

Under the VAR specification in table 3C2.1, the evidence that a positive technology shock triggers a RER depreciation is strongest for the European countries. By contrast, Table 3C2.2 suggests a RER *depreciation*, for both European and non-European countries. Note especially that table 3C2.1 suggests that a U.S. technology shock triggers a U.S. RER *appreciation*—consistent with CDL's findings. However, table 3C2.2 seems more suggestive of a U.S. RER *depreciation*; eg, under the five-variable VAR in panel (b) of table 3C2.2, the posterior probability that a RER^X depreciation occurs two years and ten years after a positive U.S. productivity shock is 80 percent. It also seems noteworthy that, by contrast to CDL, *all* specifications here suggest that (in Japan) a country specific technology shock induces a RER *depreciation*.

Summary

The results here support the finding that a positive country-specific technology shock raises a country's labor productivity, output, and private consumption (relative to rest of the world aggregates). For the larger sample of thirteen countries here, there is less evidence (than in the sample used by Corsetti, Dedola, and Leduc) that a positive technology shocks triggers a fall of net exports. Most importantly, the results here seem more consistent—than those of CDL—with the view that a positive country-specific technology shock induces a real exchange rate depreciation; this holds especially for the export-prices-based real exchange rate. Overall, the evidence here supports the conventional view that an exogenous increase in a country's supply of traded goods *worsens* its terms of trade.

Data Sources

The data on manufacturing output, and on manufacturing labor productivity (per hour worked) were downloaded from the U.S. Bureau of Labor Statistics website. The remaining data were taken from the IMF's International Financial Statistics database. "Rest of the world" (ROW) productivity, output and consumption, from country *j*'s viewpoint, are weighted geometric averages of variables of the remaining twelve countries included in the sample. Country *j*'s real exchange rate (RER) is a trade-weighted geometric average of bilateral RERs between *j* and the remaining countries in the sample. Trade weights computed by the Bank of International Settlements (downloaded from the BIS web site) were used. The BIS weighting matrix is based on trade data for the period 1990–92; it includes a larger number of countries than the study here. The countries that are not included here were dropped from the weighting matrix, and the matrix was normalized to ensure that weights sum to unity.

Notes

1. Several recent papers have used VARs to estimate the effect of technology shocks, on domestic variables (Galì 1999; Dedola and Neri 2004).

2. No quarterly series for the measure of manufacturing labor productivity used here (output per hour worked) seem to exist for the entire set of countries.

3. Augmented Dickey-Fuller tests (not reported due to space constraints) fail to reject the hypothesis that the variables (in levels) follow unit root processes.

4. For each country, I estimate a VAR in $Z^C_{j,t}$, and a VAR in $Z^X_{j,t}$ (NB $Z^C_{j,t}$, [$Z^X_{j,t}$] is the vector of variables that includes the CPI based [export prices based] RER). Responses of $x_{j,t}$, $Y_{j,t}$, $C_{j,t}$ and $NX_{j,t}$ are very similar across those VARs. The responses of $x_{j,t}$, $Y_{j,t}$, $C_{j,t}$, $NX_{j,t}$, $RER^C_{j,t}$, reported below are based on the VAR in $Z^C_{j,t}$; the responses of $RER^X_{j,t}$ are based on the VAR in $Z^X_{j,t}$.

5. I experimented with VARs of order zero, one, two, three, and four. The results do not depend on the order of the VAR.

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